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Acetylene Association Elects Hayden

E. J. Hayden, Central Division Manager of The Linde Air Products Company, Chicago, Illinois, was elected President of the International Acetylene Association at its annual business meeting held in Philadelphia, November 18th. Mr. Hayden was Vice-President of the Association.

H. B. Pearson, Compressed Industrial Gases, Chicago, was elected Vice-President to succeed Mr. Hayden. The following Directors were also elected:

W. C. Keeley, Jr., National Carbide Corporation, New York; W. H. Ludington, Air Reduction Sales Co., New York; H. S. Smith, The Prest-O-Lite Co., Inc.; C. A. McCune, *Industry & Welding*, New York; W. D. Flannery, Harris Calorific Sales Co., New York; L. F. Loutrel, Shawinigan Products Corp., New York; A. J. Fausek, Modern Engineering Co., St. Louis, Mo.; Philip Kearney, K-G Welding and Cutting Company, New York.

Exposition on Welding and Heat Treating

The Northwest Chapter of the American Society for Steel Treating and Manufacturers' Association of Minneapolis held the Second Annual Exposition on Welding and Heat Treating on December 1st, 2nd and 3rd, at the plant of the Caterpillar Tractor Company, Minneapolis. The program included papers on "Welding Rods," by Stuart Plumley; "Experiments with Liquid Air," by G. W. Irwin; "Restoration and Maintenance of Plant Equipment," by F. G. Outcalt; "Steel and Its Heat Treatment," by W. I. Sweet; and "Electric Arc Welding," by J. E. Colbert. In addition to the exhibits there were demonstrations on bronze welding, welding of malleable iron, steel, aluminum, chromium alloys, non-ferrous metals, as well as pipe welding, hard surfacing, spot welding, gas cutting, reclamation of defective castings, heat treating and annealing.

Purdue Welding Conference

Eighth Annual Conference on Welding was held at Purdue University, Lafayette, Indiana, on December 8–9, 1932, under the direction of the Engineering Extension Department and the Department of Practical Mechanics, with the Manufacturers of Welding Equipment cooperating. The attendance in 1931 was 250. This two-day educational meeting consisted of exhibits, demonstrations and talks of interest to users of electric or gas welding in manufacturing, maintenance and repair operations.

Alloys of Iron Research

The first of the Alloys of Iron Research Monograph Series, edited by Frank T. Sisco and sponsored by the Iron Alloys Committee of The Engineering Foundation, has recently been published by the McGraw-Hill Book Company, Inc.

These monographs are a concise but comprehensive critical summary of research on ferrous alloys as reported in the technical literature of the world. They contain a discussion of all available data on binary and higher ferrous alloy systems, on the effect of the alloying elements on carbon steel and on simple and complex alloy steels and special alloy cast irons. They provide a reliable foundation for further research and in one volume supply to the practical metallurgist, steel worker, foundryman and engineer the essential information now scattered through more than two thousand journals and text-books in many languages.

Engineering: A Career—A Culture

"Engineering is the most universal profession," declares the foreword of a pamphlet prepared by the Education Research Committee of The Engineering Foundation. Addressed to young men and to parents and teachers, the pamphlet, entitled "Engineering: A Career—A Culture," clarifies for youth the broad field of engineering.

The professional functions of the engineer are stated with the precision which accompanies intimate knowledge of engineering in theory and practice. The major divisions of engineering are dealt with from this standpoint, the text being, "descriptive of the profession of engineering—of its spheres of action, of the training and the qualities required for its successful pursuit, of the obligations which it imposes and the rewards which it affords."

The pamphlet carries the discussion of engineering as a profession to higher levels than have yet been attained by works of this character. The cultural aspects of engineering, too long obscured, are clearly brought out. The authors put no limitations upon the cultural possibilities inherent in engineering, which in this respect they rank with the fine arts. In so doing they dissipate illusions as to the quality and direction of the engineering mind.

"Contrary to common opinion," they say, "engineering education possesses cultural values comparable to those which inhere in the fine arts. The significance of engineering is made clear in order to aid a young man in deciding whether through this profession he can realize his ideals and ambitions."

For the first time, perhaps, an authoritative and comprehensive exposition of the engineer's vocation has combined realism with romance, utility with culture. This task has been accomplished with such skill and so great fidelity to fact that throughout the nation's educational organization engineering should take on new meaning and fresh inspiration. Engineers themselves will no doubt find that they have ascended greater heights and are facing larger opportunities and graver obligations than they had imagined.

Discussing engineering requirements and opportunities, the pamphlet develops the thesis that "engineering, the work of professional engineers, is one of the arts which interpret and apply science and experience through material things and human abilities." While engineering applies experience by the methods of science, it also does much more, it is pointed out. Indeed, engineering activity, actual and potential, seems broad enough to touch every significant phase of life.

Within the boundaries of engineering, it is explained, are five major fields, and within these some forty-two distinct divisions are recognized by the State of New York. "Dozens of others clamor for recognition. Indeed, the tendency toward specialization by men basically trained in the fundamentals of one of the major branches has become the rule."

To each major field a chapter is devoted. Civil engineering, mechanical engineering, mining and metallurgical engineering, electrical engineering and chemical engineering are comprehensively described from a professional standpoint. The work of the engineer in each of these fields is revealed as something which transcends mere professional tasks. Illustrations show the diversity, the importance and the daily usefulness of the services of engineering.

The authors have succeeded not merely in providing guidance for the young. They have attained a greater end, for these five chapters not only portray a profession but unfold a drama. In engineering, the description suggests, may lie the seeds of an epic of American life.

The members of the Education Research Committee and the societies cooperating in the preparation of the pamphlet are:

Harvey N. Davis, American Society of Mechanical Engineers, chairman; Walter F. Whittemore, American Society of Civil

Engineers; Thomas T. Read, succeeding William B. Plank (Charles H. Fulton, alternate), American Institute of Mining and Metallurgical Engineers; Walter S. Rodman, American Institute of Electrical Engineers; R. I. Rees (H. P. Hammond, alternate) and Joseph W. Barker, Society for Promotion of Engineering Education; Alfred H. White, American Institute of Chemical Engineers; Alexander R. Stevenson, Jr., The Engineering Foundation. James T. Grady, of Columbia University, is literary adviser and D. H. Killeffer, editor.

Engineers' Council for Professional Development

Seven national engineering bodies have organized the Engineers' Council for Professional Development with the announced objective of advancing the professional status of the engineer. The participating bodies and their representatives are:

American Society of Civil Engineers: J. Vipond Davies, Harrison P. Eddy, C. F. Loweth.

American Institute of Mining and Metallurgical Engineers: Donald F. Irvin, D. H. McLaughlin, Benjamin F. Tillson.

American Society of Mechanical Engineers: C. F. Hirshfeld, J. H. Lawrence, W. E. Wickenden.

American Institute of Electrical Engineers: Charles F. Scott, C. O. Bickelhaupt, L. W. W. Morrow.

American Institute of Chemical Engineers: H. C. Parmelee, A. B. Newman, John M. Weiss.

Society for the Promotion of Engineering Education: Robert I. Rees, H. P. Hammond, Dugald C. Jackson.

National Council of State Boards of Engineering Examiners: D. B. Steinman, T. Keith Legare, P. H. Daggett.

This new agency plans to coordinate and promote efforts directed toward higher professional standards. Its immediate objective is the development of a system whereby the progress of the young engineer toward professional standing can be recognized by the man himself, by the profession and by the public through the development of those qualifications which render the engineer a valuable member of society. It is believed that this will involve increased development along social, economic and general cultural lines as well as the maintenance of high technical standards of education and practice.

The Engineers' Council for Professional Development is embarking on a program of improving means for educational guidance of young men with respect to the engineering profession, the formulation of criteria for colleges of engineering, the determination of a program of personal and professional growth for young engineering graduates and the formulation of methods whereby engineers who have met suitable standards may receive corresponding professional recognition.

Four committees have been appointed to carry on this program. They are:

The Committee on Student Selection and Guidance with Harrison P. Eddy, Consulting Engineer, Boston, Mass., as Chairman.

The Committee on Engineering Schools with Dr. Karl T. Compton, President, Massachusetts Institute of Technology, as Chairman.

The Committee on Professional Training with Robert I. Rees, Assistant Vice-President, American Telephone and Telegraph Company, as Chairman.

The Committee on Professional Recognition with Conrad N. Lauer, President, Philadelphia Gas Works, as Chairman.

SECTION ACTIVITIES

BOSTON

The opening meeting of the season was held Friday evening, October 28th, in the welded office building of the Edison Electric Illuminating Company of Boston. A combination program of talks and inspection trips was offered at this meeting. Through the courtesy of Hugh Nawn, Inc., Mr. J. R. Mason spoke on American and European Methods of Welding and Testing Pipe, with particular reference to the procedure used on the mains of the steam service distribution system of the Boston Edison Company, illustrating his talk with diagrams and typical weld coupons. Mr. N. S. Wade, Assistant Superintendent of the Steam Heating Service Department, gave a history of Edison Steam Service, discussed the reasons for that company's going into steam heating service on a large scale and described the Kneeland Street Steam Generating Plant. At the conclusion of the meeting, a trip was taken through this plant.

The third and last speaker of the evening was Mr. Pierce of the Emergency Planning and Research Bureau, Inc., who explained the work being accomplished by this Bureau which is the only one of its kind in existence. This Bureau is located on the third and fourth floors of the Edison building, and all attending the meeting had an opportunity to visit these floors and see the interesting and valuable work being accomplished there.

The November meeting of the Section was held on Friday, November 18th, at 7:30 P.M. in the rooms of the Engineering Societies of Boston, 715 Tremont Temple. Six reels of motion pictures (The Arteries of Industry) were shown through the courtesy of the National Tube Company and gave the complete story of welded pipe and tube from mining the ore to the finished product. Mr. L. J. Gelshenen, of the National Tube Company, gave an introductory talk previous to the showing of the films.

The December meeting of this Section will be held Friday evening, December 9th at 715 Tremont Temple. Mr. A. G. Leake, President of Leake & Nelson Company, Bridgeport, Connecticut, will speak on "Reenforced Bridges."

CHICAGO

Talks on the proposed welding exhibit at the Rosenwald Museum of Science and Industry and on two-ply steel featured the meeting of the Chicago Section of the AMERICAN WELDING SOCIETY, held Friday, November 18th, at 7:30 P.M., in Private Dining Room No. 13, on the Club Floor, Palmer House, Chicago.

Mr. O. T. Kreusser, Director of the Rosenwald Museum gave an illustrated lecture on the value of the Rosenwald Museum in spreading knowledge of industrial processes, in which he discussed proposed exhibits and demonstrations of welding materials and welded construction and included a description of a welded coal tipple to be exhibited at the museum.

"Stainless-Clad Steel" was the subject of another talk at this meeting, with Mr. W. W. Patrick, Chief Metallurgist of the New Castle, Indiana mill of the Ingersoll Steel & Disc Company, as speaker. Mr. Patrick showed samples of this mild steel, one surface of which is a stainless steel corrosion-resistant alloy. The use of clad materials such as this one is spreading rapidly because of economies and because such materials are new and therefore their fields of application have barely been scratched.

The meeting was preceded by the usual dinner served at 6:00 P.M.

DETROIT

A meeting of the Detroit Section was held on Thursday, December 1st, in the plant of the American Blower Corporation, 6000 Russell Street, Detroit. Mr. G. E. Phelps, Applied Engineering Department, Air Reduction Sales Company, presented a paper on "Cutting Steel Shapes with the Oxyacetylene Torch Machine." This was followed by a discussion in which Mr. Phelps answered questions in a practical manner, drawing upon the experiences gained in following a specialized line of work. A demonstration followed on machines especially set up for this meeting.

LOS ANGELES

Regular meeting of the Los Angeles Section was held Thursday evening, October 20th, at the Mona Lisa Cafe.

Mr. Paul Jeffers reported on revisions to Pacific Coast Building Code, sponsored by the California State Chamber of Commerce.

Mr. T. C. Smith reported the work on State Pressure Vessel Code is still in progress, and the rough draft of same is now practically completed, lacking chiefly in details covering existing vessels. California Code should appear about January 1933, but the Los Angeles Section, AMERICAN WELDING SOCIETY, will receive definite report before this date.

(*Continued on p. 34*)

The Design and Construction of an Arc Welded Naval Auxiliary Vessel*

By HOMER N. WALLIN *and* HENRY A. SCHADE

†Paper presented at August 9, 1932 Meeting of Los Angeles Section, American Welding Society, by V. M. Goode, C.M.M., U. S. S. *Medusa*. Lieutenant-Commander Homer N. Wallin and Lieutenant Henry A. Schade are Shipbuilding Superintendent and Assistant Shipbuilding Superintendent of the Construction Corps, U. S. Navy, Navy Yard, Mare Island, California.

ARC welding has been in general use by the Navy, principally on repair work, since the epoch-making war days when the sabotaged engines of seized German liners were salvaged by this comparatively new art. It is only since the displacements of naval vessels have been limited by international treaties, however, that the Navy has begun to look upon arc welding as a standard method of construction. Displacement limitations being equivalent to weight limitations, naturally place a premium on methods of construction by which weight may be reduced without loss of desirable characteristics. With this impetus, arc welding is supplanting riveting over a wide range of applications in increasing amounts on each new ship designed by the Navy, as it becomes more and more evident that lighter structures of equivalent strength, rigidity and shock resistance may be obtained by this process.

A movement toward the construction of ships of large dimensions entirely by welding is developing along two lines, viz., the increasing partial use of the process on large ships and the complete substitution of welding for riveting on small ships. The Navy Department has extensively participated in both phases, first entering the latter in 1930 when it authorized the construction of two motor tugs, two self-propelled garbage vessels, two seaplane wrecking derricks and several smaller vessels by by the all-welded method.

The construction of one of these craft, a garbage vessel, was undertaken at the Navy Yard, Mare Island, California, and completed on September 15, 1931. The hull of this vessel as shown in Fig. 1 has a conventional ship-

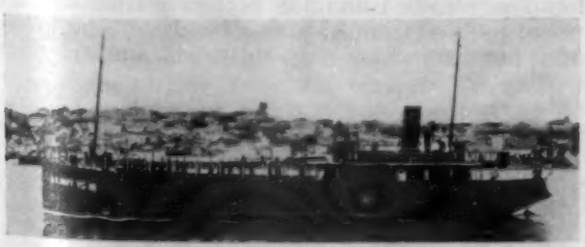

Fig. 1—The All-Welded Naval Vessel Described on a Trial Run

* This is a brief of a paper by Lieutenant-Commander Wallin and Lieutenant Schade which was awarded first prize in the Second Lincoln Arc Welding Prize Competition sponsored by The Lincoln Electric Company, Cleveland, Ohio. Lieutenant-Commander Wallin and Lieutenant Schade were awarded $7500 for their paper and in its original form it consists of approximately 70 pages of typewritten description, data and photographs. The complete paper with other prize-winning papers will be published in book form by the sponsors.

NUMBER	SIZE OF WELD	TYPE OF JOGGLE	BREAKING LOAD LBS.	BREAKING STRESS LBS/SQ.IN	LOCATION OF BREAK.
1	1/4	SHORT	64120	42735	
2	3/8	"	84160	56100	
3	"	"	80000	53330	
4	"	"	79000	52660	
5	"	"	78150	52120	
6	"	"	75760	50500	
7	"	"	82000	54660	
8	1/4"	"	66200	44130	
9	"	"	60100	40000	
10	3/8"	LONG	91280	60850	
11	"	"	86640	57760	
12	"	"	89230	59480	
13	1/4"	"	71000	47330	
14	"	"	78000	52000	

Fig. 2—Test Results of Various Joggled Lap Joints

shape form with straight vertical stem and transom stern, a length of 118 ft., beam of 25 ft. and full load draft of 5 ft. 3 in. The carrying capacity is 125 tons, which gives a full load displacement of approximately 300 tons. The power plant consists of a 240-hp. Diesel engine which was removed from one of the "K-Class" submarines recently scrapped; the speed of the craft is about ten knots.

As the Navy is interested only technically and not competitively, it is believed that a great deal of good can be done in the field of electric welding by making available complete information on the design and construction of this vessel. Lap joints were adopted for all shell seams, and, as a general rule, for all other plate seams throughout the ship. The joggled lap was used, which allows all bulkheads and internal framing to be worked to the molded line. The arguments for lap joints hold for plate butts as well as for seams; however, strapped butt joints were used in order to gain experience with both types of joint.

A number of tensile tests were made for the purpose of determining the best design for the plate seam lap joints. Specimens were made from $^3/_8$-in. medium steel plating which on test showed an average tensile strength of 59,630 lb. per sq. in.

All specimens failed under tension in the plate rather than by failure of the weld and all but one fractured adjacent to a line of welding. Test results with the various types of joints are shown in Fig. 2.

While the tests actually made were not sufficiently comprehensive to establish definitely the relative values of the features under consideration, they provided fair indications of what might be expected and consequently furnished a basis for the design of lap joints to be used. It was decided to use a $1^1/_2$-in. lap with a full fillet weld on each side of the lap and to use the long joggle.

The longitudinal bar frames (or longitudinals) along

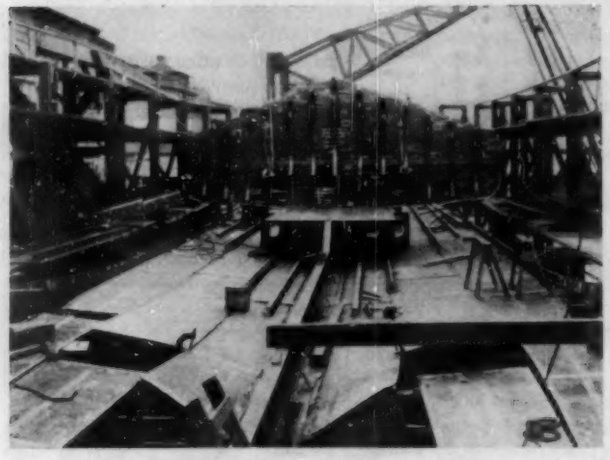

Fig. 3—Lowering a Bulkhead into Position

the shell, deck and hopper are 3 in. x 5 in. x $1^5/_8$ in. x 6 in. angle bars, with the edge of the wide flange against the plating. They are spaced about 2 ft. apart and fall on each plate lap and along the middle of each plate. The transverse web frames (or transverses) are spaced from 5 to 7 ft. apart. Each transverse is built up of a web about 18 in. deep with a symmetrical face plate, double fillet welded normal to it. The connections between the longitudinals and the transverses or bulkheads are locked together at points of intersection. The transverses and bulkheads are slotted to take the standing flanges of the longitudinals and the face flanges of the longitudinals are slotted to take the transverses and bulkheads. This results in intercostal face flanges and continuous standing flanges and the meshing of the slots forms a "lock-joint." Bulkhead stiffeners are spaced to connect by means of brackets to the longitudinals on the bottom plating and under the deck or hopper plating. They consist of 3-in. x 4-in. angle bars with the standing flange forming a T-joint against the bulkhead plating.

The longitudinals, transverses and bulkheads form T-joints with the shell. The first two were intermittent welded, using the chain arrangement, and the boundaries of the water-tight bulkheads were continuous fillet welded on both sides. The T-joints between the standing flanges of the bulkhead stiffeners and the bulkhead plating were also intermittent chain welded. The "lock joints" between the longitudinals and the transverses were welded on the outside of the bar only, as watertightness is not required. Intermittent welding was used where neither watertightness nor maximum strength is required. The usual method of holding the parts together before welding is to use bolts and bolt holes; the procedure is much like that for a riveted ship, except that fewer bolts are used. It is necessary to lay out and punch the holes in the shop, bolt upon the ways, remove the bolts after welding and usually to weld up the bolt holes after they have served their purpose. Although this method has apparently been generally used, the decision was made to assemble and erect this vessel without the use of assembly holes for bolts. This decision was influenced by the fact that bolts and bolt holes are applicable only where both faying surfaces can be punched, which could be done on this vessel only on plate seams and strapped butts.

Originally it was intended to use the system of tack welding employed by some of the German shipyards, consisting of very small tack welds about the size of a pea, called "pea" welds, spaced about a meter apart. Tack welds of this size provide a bond which is purposely so weak that the tack welds break in case appreciable stresses develop in the joints during the finishing welding. It was very soon discovered that such "pea" welds are not strong enough to resist even very small shrinkage stresses. The system was modified and "string" welds were used for tacking, having a length of about 1 in. and a nominal size of $^1/_8$ in., spaced about 12 in. apart. These tacks are strong enough to hold the parts but weak enough to break when shrinkage stresses become excessive.

All welders assigned to the job were first-class welders who had successfully passed the standard qualification test on numerous occasions. Welders were constantly supervised not only in regard to the size and quality of the welds but also in connection with proper current values, cleanliness of the welding surfaces and proper size rod.

It was the practice to assemble and weld up in the shop as many units as considered practicable and advantageous, especially flat assemblies such as bulkheads, transverses and hopper plating.

After experimentally assembling and welding two bulkheads on an I-beam platform, all remaining bulkheads and flat assemblies were assembled and welded on the bending slab. By using this method, warping of the edges of the plates is easily restrained by dogging them down. Furthermore, the plates being supported at practically every point, there is no tendency to distort resulting from sagging of plates between supports, as there is on the I-beam platform. The intimate contact between the plates and the slab, which is an excellent heat conductor, appears to assist in reducing the heated areas by conducting the heat rapidly away and this also reduces the tendency to distort. The units are easier to assemble on a flat surface than on the I-beam platform and the use of a heavy roller for forcing the laps together is made possible.

In order to compensate for shrinkage, the boundaries of the flat assemblies were left 1 in. oversize. After shop welding was completed, the mold was applied and the boundaries marked for trimming. On the bulkheads the water lines and buttock lines were remarked on the smooth side to insure accurate lines for properly locating the bulkheads during erection.

The vessel was constructed on keel-blocks adjacent to one of the drydocks in suitable position for side launching after being skidded to the edge of the dock. After the three keel sections had been laid on the keel-blocks the bottom plating was laid out in a cradle which was built an inch or two lower than the final location of the plating, after which the seams and butts were tack welded. The bottom longitudinals were next set in position and tack welded. Each completed transverse bulkhead and transverse was erected in its proper location, plumbed and the bottom plating shored or pulled to it. Figure 3 shows a bulkhead being lowered into position. Since the bulkheads and transverses

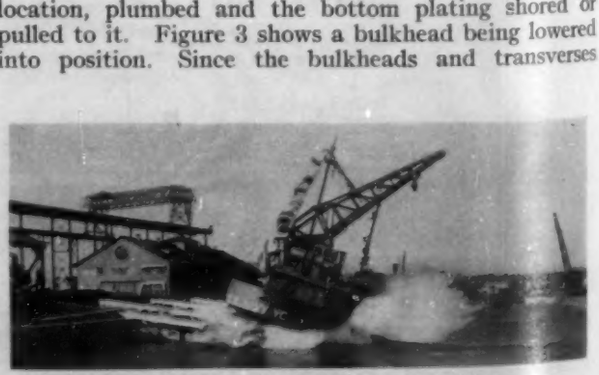

Fig. 4—Side Launching Was a Severe Test on Welded Joints

were slotted to take the longitudinals, and the latter were slotted to take the former, it was not difficult to set these transverse parts in their proper locations. When most of the bulkheads and transverses had been erected, the side longitudinals were placed in position in the proper slots. The hopper plating was placed in position as soon as all the bulkheads and transverses supporting it had been erected. After the bulkheads and transverses extending above the hopper deck had been erected, the side plating was carried up to the sheer strake. Finally, the deck longitudinals and deck plating were placed in position.

This was accomplished by a variety of methods depending on the conditions. Shores, clamps, wooden wedges, levers, weights and chain falls were all effectively used. Where the plates had considerable shape it was sometimes necessary to tack weld a bolt to one part and a clip, through which the bolt could pass, to the other. The use of an air jam backed up by staging proved very successful in forcing plates against framing. On the whole there was very little difficulty in bringing the parts into satisfactory contact for tack welding, and the methods employed were considerably cheaper than the general use of bolts and bolt holes would have been.

The men used are welders capable of both arc welding and gas cutting. One was assigned with each shipfitter, and, when thus assigned, did no finish welding whatever. His duties were to do gas-cutting, tack welding and temporary welding such as clips, etc., as required by the shipfitter and, when not so employed, to assist the shipfitter in a capacity similar to that of a helper. This system eliminated much lost time, since shipfitters were never waiting for a burner or a welder and welders were not interrupted by calls from the shipfitters to do tacking or temporary welding. One gang composed of shipfitter, helper and combination welder could do the entire job of preparing a part of the structure for the finish-welders after the riggers and shipwrights had done the necessary erecting and shoring.

Since the weather decks have both camber and sheer, fabrication and welding in the shop would have involved mocking up to shape during welding, and this would lose much of the advantage obtainable by dogging down plating to the slab as was done with the bulkheads. Consequently, this work was done on the ways and, although it involved a large amount of overhead welding where the longitudinal deck beams weld to the docks, this was not considered a serious problem; the welders apparently are able to produce overhead work very nearly, if not entirely, equal in quality and quantity to work done in the flat position. When decks are welded up on the ways it is best to leave the margin oversize for trimming after welding.

The launching as shown in Fig. 4 constituted a very severe test of the vessel's ability to stand shock and sudden pressure, as in the side launch there was a vertical drop of about 3 ft. 3 in. between the end of the ways and the surface of the water. Since the draft of the vessel at launching was 2 ft. 9 in. this means that there was a total vertical drop of about 6 ft. between the position of the vessel at the ends of the ways and the position at rest in the water. A very careful examination immediately after launching disclosed no leaks and no evidence whatever of any structural weakness.

The obvious and outstanding advantage of welding over riveting in ship-building consists in the saving in weight of structural hull material.

The increased weights of the elements of the riveted hull, expressed as percentages of the weights of the corresponding elements of the welded hull, are itemized below:

Longitudinal frames and beams	43%
Bulkheads	22%
Docks	11%
Shell plating	3%
Transverses	0%

When each of these percentages is multiplied by the fraction which the welded element is of the total weight of the welded hull, and the results added, the riveted hull is found to be 17% heavier than the welded hull.

In the cost comparison which follows, the cost figures for the welded vessel are the actual costs to the Government exclusive of the machinery units. These costs are divided into their elements, labor, overhead and material.

Cost Comparison of Welded and Riveted Ships

Item	Welded Ship	Riveted Ship
1. Mold loft work	$5178.00	$6370.00
2. Pickling and painting of structural steel	1227.87	1436.00
3. Fabrication and erection of steel hull	28474.15	42890.00
4. Welding (or riveting) of steel hull	11884.75	11425.00
5. Cleaning steel in way of welding	509.73	—
6. All other items except machinery	61606.29	61606.29
7. Sub-total (hull and fittings complete, without machinery)	108880.89	123637.29
8. Machinery items (except cost of units)	18860.51	18860.51
9. Grand total (except cost of machinery units)	127741.40	142497.80

The difference between the two totals is $14,756.40 which is the minimum saving in first cost obtained by using welding instead of riveting on this vessel. Comparing this with the total cost of the riveted vessel (exclusive of machinery units) the saving is slightly over 10%.

In addition to this first saving in cost there are other savings which cannot be so explicitly stated in terms of dollars. The riveted ship, being 17% heavier, has a correspondingly reduced carrying capacity and the welded ship, therefore, yields greater service for a smaller investment; fewer trips need be made to do the same work, thus reducing the cost of operation and upkeep costs for wear and tear. Throughout its life the riveted ship has 41,525 lb. more structural material to be pushed through the water. This means that when the welded ship is loaded to capacity, less fuel is required for each pound of useful load; when the welded ship is empty, fuel is saved as compared to the riveted ship, on account of lighter displacement. The total savings, direct and indirect, during the lifetime of the vessel will be enormous, and out of all proportion to the saving in first cost. It is apparent that there is no field in which arc welding offers greater financial opportunities than in the construction of ships.

In the near future the saving in first cost is certain to be even more favorable than at present, due to improved design of details of welded structures, better welding equipment and increased production by the welders. Welding machines of greater capacity, "high-speed" electrodes and various automatic features are already assisting in stepping up production. Although arc welding is today recognized as a standard method of economical construction in many fields, its real development and application have barely begun.

Recent Advances and Future Expectations of the Oxyacetylene Process

By JAMES H. CRITCHETT

†Paper read before the 33rd Annual Meeting, International Acetylene Association, Philadelphia, Pa., November 16, 17, 18, 1932, by J. H. Critchett, Vice-President Union Carbide and Carbon Research Laboratories, Inc., New York.

TO DISCUSS the subject of oxyacetylene welding under this title, one should be the seventh son of the seventh son for those are the ones who have the gift of prophecy. Most prophets have been old men and I do not want to consider myself in that group yet. Nor do I want to live to a ripe old age if to do so requires following the centenarian who on being questioned as to how he had achieved so many years replied that it was simple. . . . . .

The fact that prophets have been old would seem to imply that knowledge of what has happened is a prerequisite to foretelling what will take place in the future, and I may lay some claim to such knowledge. So let us take a look at what has been going on recently in oxyacetylene welding. Let us take off from the time when the oxyacetylene blowpipe had become a well-developed tool, reasonably priced and with ample supplies of gases readily available.

Since then, from being a repair tool called in for emergency use, the oxyacetylene blowpipe has become, in addition, a production tool enabling the quicker, cheaper and more satisfactory manufacture of a superior type of product. This is true in factory or in the field, under mass production methods and under conditions requiring occasional small lot production. Whether the skill required by the job is that of the mechanic, the artisan or the artist, the quality of the product has become so well recognized that one by one the barriers of national and local codes and insurance and safety rules have fallen before the insistent demand for its use.

The oxyacetylene method of applying hard-facing has enabled the metallurgist to compound metals with little regard to the cost of the ingredients. The homeopathic amounts used at the exact point of need make even the most costly compound economic in the end. Thus, millions of dollars worth of heavy duty machinery is protected by hard-facing. Oil well drills can be kept in service thousands of feet under ground for long periods without having to be withdrawn for dressing; grinding mills continue to turn out their product at lower cost and industry is served in numerous other ways.

The once strictly neutral flame became first excess acetylene to enable quicker melting and faster production on steel welding and next excess oxygen to permit the better welding of brass and bronze.

The cutting blowpipe, once chiefly the ally of the wrecker, became the tool of the builder. By application of machine control a once undreamed-of accuracy of size and smoothness of cut became an every-day fact. Today oxyacetylene cutting rivals in finish any but the most perfect of machined cuts; its accuracy is sufficient for by far the bulk of manufacture. Similarly the oxygen lance once used to dismantle large masses of metal became refined into the scarfing blowpipe for removing imperfections from the surface of billets and slabs in the process of steel rolling. Thus, the chipping dock, long the bane of the steel mills, fades into the realm of forgotten ills.

Much more could be added but perhaps sufficient has been said to lay the ground for an attempt to look into the future.

First, as to the tool itself, the oxyacetylene blowpipe. Already signs of change are appearing. The old "burner" has gotten itself into new surroundings. No longer are both hands of the welder required properly to manipulate the blowpipe and welding rod and thereby the nervous strain incident to welding is greatly reduced and the speed of welding markedly increased. But much greater changes are to be expected. The efficiency with which the heat of the oxyacetylene flame is used in welding leaves room for much improvement. We can be certain that our technologists will find the means to harness better the heat, now only partially employed, and the new blowpipe will need less gas for a much greater hourly output of welding. Ten years from now the present blowpipe will look as antiquated as would today the old horseless buggies which some of us can still remember.

Next, let us try to see what the improved oxyacetylene equipment will be doing that is not being done today. Certainly it will be welding new materials. In the age that is before us metals will be used to an even greater degree than now. Within our lifetime steel will continue to be the chief metal employed but it may not be the steel with which we are familiar. Just as the stainless steels have recently come to the front, other new varieties with improved characteristics will appear in the future. As the kinds are multiplied, each variety will be used where its specific qualities are needed and structures and machines will be put together from a greater variety of steels than is now common. This presents both a problem and an opportunity to oxyacetylene welding. Past successes, due to the adaptability of our process, point the way and it is up to us to determine how much of this assembling shall be by welding. Oxyacetylene welding has the opportunity, because of its unequaled ability, to weld many different materials, to hold the leading position, but it will only do so if we successfully strive to solve the problems inherent in the new materials and the improved methods of construction.

Other metals also will come more to the fore. Already the way is set for the much wider use of aluminum and its alloys, a development in which gas welding will be prominent. Also, copper base metals probably will take a larger part in our civilization. Copper is too cheap today but with the new low cost, large tonnage mines which have come in during the past decade, it is not likely either that its price will rise to former levels or that copper producers will be satisfied until their product is more widely used. New alloys of copper are known which develop the strength and ductility of steel and respond to heat treatment as does that material. These and other copper alloys which can be confidently predicted will do much to broaden the uses of that metal. And here again, welding is the best method of fabrication and oxyacetylene the best method of welding.

Less clearly predictable but almost as certain of realiza-

tion is the use of plastics and glasses in new ways. The construction of large glass chemical equipment or the facing and ornamentation of buildings may be examples. Some predict glass furniture but from my experience with the frailties of even the strongest wooden chairs, I cannot look forward to that prospect with equanimity. Plastics are certainly forging ahead with great strides. Whatever the material, sometime, somewhere the problem of joints must be faced. Oxyacetylene welding is a perfectly reasonable answer if we who are keenly interested in the process have the vision, wisdom and energy to grasp the opportunity.

To get back closer to the ground, however, the newer techniques of blowpipe adjustment and manipulation certainly open new opportunities in familiar fields. Bearing metals now can be deposited and non-ferrous, metal-faced steel bearings are possible. But chiefly, I think, these changes point to a machine welding development. Speeds of welding are today taxing the ability of human eye and nerve to keep pace with them. A little further increase and machines controlled automatically to insure sound welding are a necessity. I look forward to this development expectantly for it should lead to larger fields of usefulness and to the elimination of many of the present problems.

Before leaving the welding field, I want to point to one other way in which use of the oxyacetylene blowpipe should increase. The type of heat developed is ideal for many kinds of heat treatment. It is now used for this purpose to some extent both locally and in production as in the heat treatment of the teeth of saws. Other applications of a similar nature exist where use of the blowpipe would be economical and an increased use of the blowpipe can be looked for in this general direction.

Equally great advances may be expected in the use of the cutting blowpipe as in the use of the welding blowpipe. Already we have seen refinements which increase the accuracy and smoothness of the cut. Little further development is necessary to make burning to shape with oxygen replace a wide range of cutting operations. One who has watched heavy machining as in a roll turning lathe, a boring mill or planer must be impressed with the costliness of the heavy machines required both to support the work under the heavy pressure of the tool and to supply the large amount of power needed by the operation. Substitution of the oxygen jet for the cutting tool will simplify the machine tool, materially reduce the power required to drive it and increase the speed with which the metal can be removed. Before this development can be carried to its logical goal, much remains to be learned about the effect of the shapes and velocity of the oxygen jet. The judicious use of preheat and even artificial chilling may also enable better control of the cut. Sufficient is known about these factors today to make a large number of applications profitable and to point the way to larger use of this means of removing metal. Undoubtedly further research and development work will expand the field until it is one of the major means of converting the output of the steel mill into the ultimate desired shape.

So much for speculation. In closing, I cannot resist the impulse to point out a few implications of what already has been said. Competition is keen, business is dull, men are contrary and often life looks very difficult and at times scarcely worth while. But we are going ahead steadily, now and then slowly to be sure, nevertheless certainly. In times such as we are now emerging from we are building for the future even better than is possible under boom conditions. This is particularly true of the oxyacetylene industry. In some fields we have met difficult competition but ours is a process with unlimited possibilities and for every foot lost there is a yard of gain. The object of this talk has not been achieved if it has failed to give you the conviction that the future of the industry is bright. But greatness is rarely reached and never held without effort and to attain our full share of growth we must be diligent. It is not sufficient to have the materials needed for oxyacetylene welding available in great quantity and of high quality. We must constantly improve our methods, search out new uses, adapt our process to the changing needs of industry, meet new developments with service and welcome the opportunity afforded our process by new materials and methods. The unique ability of oxyacetylene welding to handle almost any material in any kind of a location and to do a superior job is cause for confidence that the future holds for us ever increasing growth and deserved prosperity.

Discussion of C. H. Jennings' Paper, "Load Test on a Welded Roof Truss"

By A. M. CANDY

†Paper presented at the Annual Meeting of the American Welding Society, Oct. 6, 1932, by A. M. Candy, Engineer, Small Motor Appl. & Welding Eng., Westinghouse Electric & Manufacturing Company.

THE last twelve to eighteen months in particular have witnessed the advancement and development of a great many ideas which show improvements both in quality and in reduced cost of many articles with which we have been familiar. The novel design of roof truss described by Mr. Jennings is one of those ideas which, when brought out, everyone wonders why they themselves did not think of it previously. The advantages of design and simplicity of parts required and weight reduction made available are too obvious to require much additional comment. For this reason, therefore, I felt that it would be of interest to direct attention for a few minutes to another new idea in building construction design, namely, that of Mr. M. G. Clark, President of Insulated Steel, Incorporated, a subsidiary of the American Rolling Mills Company. The development in question is the production of a frameless steel house. The entire shell of the house is constructed of Nos. 16-, 18- and 20-gage Armco iron arranged in a very novel form of design. A house involving this design is just being finished in Solon, Ohio, one of the suburbs of Cleveland. This house contains approximately 17 tons of steel.

Shop Forming

The entire structure is constructed of a relatively few standardized sections and sub-assemblies readily fabricated with a minimum of capital investment in tools and machinery.

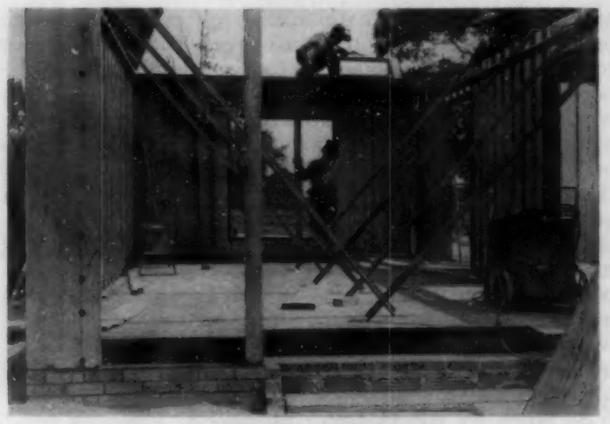

Fig. 1—Assembling First Floor

The flooring system is surprisingly simple and unique, being formed in individual pieces in a bending break to the so-called Z-form, although the planes are at 90° with each other. The length of the section is determined by the span requirements. The section is made of No. 18-gage steel with 11-in. legs and a 6-in. web member.

The outside wall section and interior foundation bearing wall section is equally simple and unique, being formed in four sizes of one, two, four and six webs on a suitable bending break. Each single section is a modified channel shape of No. 20-gage sheet steel, the web portion being 6 in. wide, the legs 2 in. with a $^1/_2$-in. lip extending from each leg parallel with the web plane. The two, four and six web sections are simply multiples except that the $^1/_2$-in. lips are, of course, only located at the extremities of the sections.

The corner assembly is likewise formed from No. 18-gage steel, the face of the web being (12 in.) double that of the wall section ribs. The legs of the section are 2 in. and are carried around to form a re-entrant $^1/_2$-in. lip. Reinforcing strips about $1^1/_2$ in. wide are located with the face of one end against the inside face of the lip and the other end abutting the interior surface of the opposite integral rib member. These strips are offset by their width at panel points and are spaced on about 24-in. centers. These strips are reinforced by an angle of No. 18-gage steel with 2-in. legs running full length of the section and being welded to the strips by fillet welds.

The window and door frames are formed of No. 16-gage "Furniture Steel" in two distinct operations one of which produces the main section design and the other of which closes the section to the final shape. This frame stock is miter cut and welded in a jig to the proper dimensions after which it is sprayed with varnish.

The bearing angle section for supporting the upper floors and which serves as an electrical conduit and cornice treatment is formed in a manner similar to that described. It is formed from No. 16-gage steel with 3-in. legs and $^1/_4$-in. lips.

Shop Fabrication

The arc welded shop fabrication is performed with a 200-ampere D.C. welder using $^3/_{32}$ in. and $^1/_8$ in. diameter covered wire at the plant of The Mills Co. in East Cleveland, Ohio. The welding is very intermittent and the welds are of short length (requiring about 5 seconds) due to the very low stresses carried by the welds. In fact the welds are, as a rule, subjected to greater stress during assembly, trucking to site and field erection than they will be in service in the completed structure.

By means of very simple jigs (subject to improvement for production), window frames, framing and wall sections are formed into the required sub-assemblies. Blank wall sub-assemblies of suitable wall sections are similarly made. To give such assemblies later stiffness the top and bottom ends are bounded by No. 16-gage steel "Header" strips 2 in. wide, fillet welded to the sections.

Before shipment to the site all sections are given a sprayed coat of aluminum paint to prevent rusting during transit and field erection. This item of expense can be reduced in several different ways for future production requirements. Each section is also given a key number to tie in with the drawings to assure rapid and accurate field erection.

Field Erection at Solon, Ohio

After the basement and foundation walls are completed, they are capped with No. 16-gage galvanized steel which extends down 2 in. below the wall top serving as an anchor to which the wall sections are welded. The outstanding lip (1 in. wide) serves as a support for the exterior insulation and finish. The floor sections are also welded at their extremities to this cap.

The first step in the actual erection work is to install the first floor system. All welding is done in a downward direction consisting of tack welds about $^3/_4$ in. long where ends are attached to the foundation cap and tack welds on 24-in. to 26-in. centers attaching each floor section to the preceding section. Each weld attaching the top edge of a floor section to the preceding section is a fillet weld and is accomplished by the operator pressing the edge into contact with his weight. Each weld attaching the lower leg of the floor section to the

Fig. 2—Showing Lightness of a Section

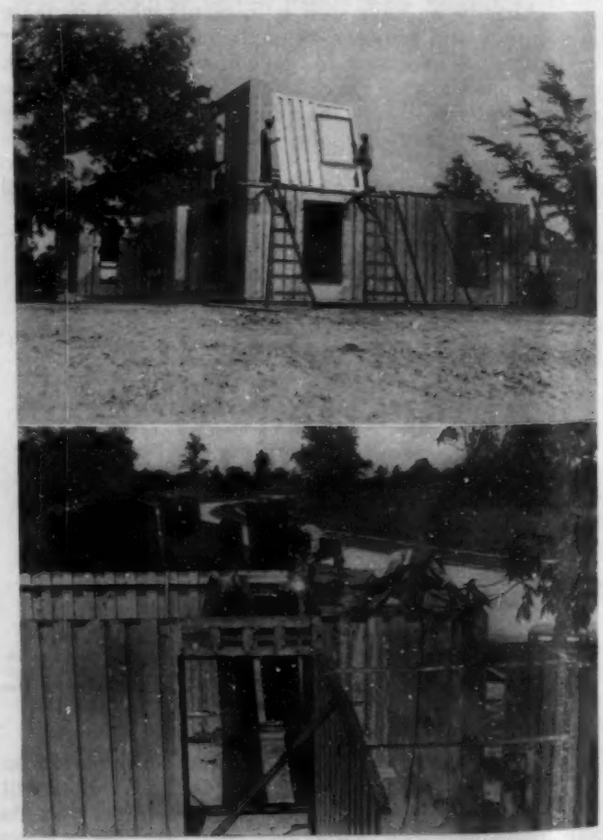

Fig. 3—Field Welding

edge of the preceding section is a "penetration weld" produced by fusing through the upper sheet into the lower sheet. The two pieces are held in contact by an assistant with a T-shape formed of 2x4 wood section, the top of the T contacting the under side of the floor section.

The spacing of the floor sections for the main floor system is on 10-in. centers. At locations where a room or other intermediate partition is required running with the length of the floor sections the overlap of the sections is increased and the 10-in. dimension is decreased to 4 in. or 5 in. so as to increase the number of 6-in. web members to carry the partition load. This illustrates the flexibility of the floor system scheme.

When the floor system is completed the wall system is erected using the sections and sub-assemblies previously described. These wall sections (8 ft. $10^{1}/_{16}$ in. high) are temporarily held in plumb position by means of the angle iron braces, the ends of which are suitably formed so they can be temporarily tack welded to the top bounding strip of the wall section and the surface of the floor system.

After the wall sections on a given side are properly plumbed and lined up, they are welded by penetration welds through the bottom header strip to the foundation cap and by fillet welds to the floor system. Then the bearing angle form for the second floor is welded to the wall sections. This angle section is welded with "penetration welds" through the vertical leg at the apex to the faces of the wall sections.

After completing the first floor side walls the second floor flooring system is installed. This is followed by the erection of the second floor wall assemblies (7 ft. $11^{7}/_{8}$ in. high). These sections are held in same manner as those for the first floor and the bottom bounding strip is "penetration welded" to the top bounding strip of the first floor wall section immediately below and fillet welded to the floor system.

These second floor wall sections and sub-assemblies like the first floor assemblies are so light (averaging 2.9 lb. per sq. ft.) that they can be very readily handled by three or four men. To elevate them to the second floor they are laid against two of the erecting brace angles inclined against the outside of the wall. Then with two men on the second floor and one or two men on the ground the sections are skidded up to the second floor where the second story men handle them into position as illustrated.

Accuracy of construction of wall assemblies is not of paramount importance because of the design of the wall sections which permits of sliding "lap adjustment" during fabrication or erection. This feature, however, is a by-product of the general wall design idea and is principally important from the standpoint of permitting the assembly of standardized sections to produce rooms of a wide range of sizes.

Accuracy of constructing wall sub-assemblies involving window and wall sections is important because, where such sections are located one above the other, it is necessary that the windows line up vertically. However, if the shop assembly is found to be "over size" it can be readily trimmed down to size with heavy tin snips due to the light gage (No. 20) of the metal.

After completing the second floor wall system the roof system using the floor sections is installed. A parapet 3 ft. high is then erected thereby completing the main steel work.

All of the field erection welding is performed with a 100-ampere alternating current welder.

Finish

After all steel work is completely erected it is sprayed inside and outside with a plastic paint. The top of the floor system is covered $^{1}/_{4}$ in. deep with an asphalt mastic in which the wood floor proper is set.

The interior is finished with wall board attached to the wall steel. Plastering is placed on the wall board and the base board is of Westinghouse Micarta plate as is also the $1^{1}/_{4}$ in. wide trim around the doors.

The exterior is finished with 1 in. thick "celotex" insulation attached directly to the outside of the wall steel. The final exterior surface is composed of the new Ferro Porcelain Enameled Tiles mounted on heavy asphalt paper which are nailed through the insulation to the wall steel with driving screws.

The flat roof is treated similarly to the floors except that slate tile are set in the mastic coating so that the roof may be used as a sun deck and play space for the children and others.

Plan

The general plan of this particular house is as shown. The appurtenances include complete electrical equipment of Westinghouse manufacture such as electric refrigerator, electric range, kitchen ventilating fan, bathroom heater and "No Fuze Load Center."

Discussion of C. H. Jennings' Paper, "Load Test on a Welded Roof Truss"

By **FRANK P. McKIBBEN, President, American Welding Society**

✦A paper presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 6, 1932.

WHILE reading Mr. Jennings' interesting article, "Load Test on a Welded Roof Truss," it occurred to me that a comparison between calculated and observed vertical deflections at the center of the truss would be of interest.

Two methods, other than by testing, are available for determining the deflection of trusses:

1. Williott's diagram gives in one graphical solution the exact motion, horizontally, vertically and finally of every joint in a truss under a given set of loads. Because it exhibits the horizontal and vertical components as well as the resultant motion of each and every joint no better method exists for ascertaining truss deflections.

2. The exact deflection of any one joint in any one direction may be calculated by a method based on virtual velocities. As this solution gives the motion only of one joint in one direction, it is not as comprehensive as Williott's diagram, but, as the vertical deflection of one joint is all that is desired in many cases, this method of calculating deflections is often sufficient. For example, in Mr. Jennings' article the observed verti-

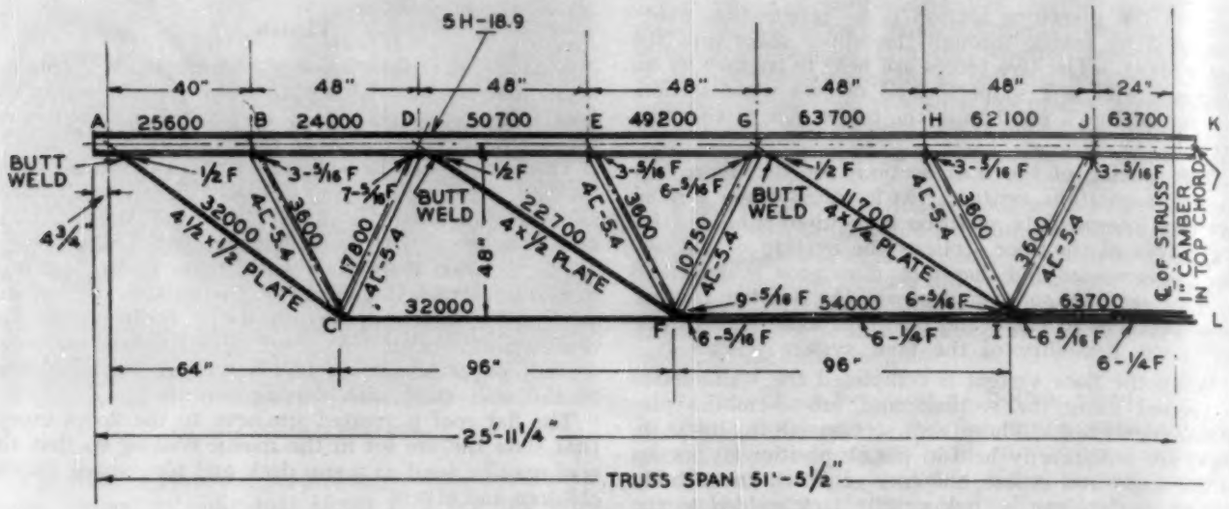

Fig. 1—Detail of Welded Roof Truss

cal deflection at center of the truss is given as 1.08 in., and approximately this amount, namely 1 in., is used as the truss camber.

As only the central vertical deflection of the truss is given in Mr. Jennings' article, the second method outlined above will be used here. To ascertain the deflection of any one truss joint in a given direction, a load of one pound is imagined at the joint, acting in the direction in which the deflection is desired. The stress in each and every truss bar resulting from this load of unity is then calculated and each of these stresses is multiplied by the change in length of the corresponding bar—such changes being due to the applied loads actually resting upon the truss.

The process may be stated thus:

$$\text{Deflection} = \Sigma t\,(\text{change in length}) \qquad (1)$$

where t denotes the stress in each bar due to the imaginary load of unity.
(Change in length) is the increase or decrease in length of each corresponding bar, respectively, resulting from its tension or compression.

When elastic deflection due to applied loads is desired, the formula (1) should be written:

$$\text{Deflection} = \Sigma t \frac{SL}{AE} \qquad (2)$$

where S = stress in each truss bar due to actual loading
L = length of each bar
A = gross cross-sectional area of each bar
E = modulus of elasticity of steel
t = stress in each bar due to the imaginary load of unity
Σ denotes the summation of the quantities StL/AE.

As only the central vertical deflection is desired for the truss in question the unit load is placed at the center of the span and the value of t is determined for each bar; + denoting tension; − denoting compression. These values of t, as well as other data, are placed in Table 1, from which the calculated value of the central vertical deflection is found to be 1.02 in., corresponding closely with the observed 1.08 in. In other words, Table 1 represents $\Sigma \frac{StL}{AE}$.

The above calculated value of 1.02 in. is only the vertical deflection of the central point. If, in any case, it were desirable to secure the true motion of the joint, horizontal as well as vertical components must be found. The resultant deflection would be the square root of the sum of the squares of these components.

Obviously, since in this case the truss and loadings are symmetrical about center line, the value of $\Sigma\, StL/A$ is taken for one-half of the truss and then multiplied by 2; and, as the modulus of elasticity E is uniform for all bars, it is introduced at the final calculation, see Table 1. Also, because the stresses, S, are given in units of 1000 lb. in Table 1, the value 1000 is introduced in the final calculation.

I have often used the above method, equation (1), for determining deflections due to the "play" in pinholes of pin-connected trusses or of bolts in bolted connections, and for deflections resulting from temperature changes.

Table 1—Calculations for Vertical Deflection at Center of Truss Due to Stresses Shown in Fig. 1, p. 14, September 1932 Issue, Journal of the American Welding Society

	+ denotes tension				− denotes compression	
Truss Bar	S,* Lb.	t, Lb.	L, In.	StL	A, Gross Sq. In.	$\frac{StL}{A}$**
AB	−25.6	−0.667	40	683	5.47	124.8
BD	−24.0	−0.667	48	770	5.47	140.8
DE	−50.7	−1.667	48	4050	5.47	739.0
EG	−49.2	−1.667	48	3940	5.47	719.0
GH	−63.7	−2.667	48	8190	5.47	1498.0
HJ	−62.1	−2.667	48	7990	5.47	1460.0
JK	−63.7	−2.916	24	4473	5.47	817.0
CF	+32.0	+0.92	96	2800	2.25	1243.0
FI	+54.0	+1.916	96	9980	4.25	2338.0
IL	+63.7	+2.916	48	8950	5.25	1700.0
AC	+32.0	+0.836	80	2130	2.25	947.0
BC	− 3.60	0	54	0	1.56	0
DC	−17.8	−0.56	54	538	1.56	345.0
DF	+22.7	+0.908	87	1785	2.00	893.0
EF	− 3.6	0	54	0	1.56	0
GF	−10.75	−0.56	54	325	1.56	208.5
GI	+11.7	+0.908	87	928	1.00	928.0
HI	− 3.6	0	54	0	1.56	0
JI	− 3.6	−0.56	54	109	1.56	70.0

$$\Sigma \frac{Stl}{A} = 14171.1^{**}$$

* In 1000-lb. units.
** For one-half of truss.

$$\text{Vertical deflection at center} = 2\,\Sigma \frac{StL}{AE} = 2\left(\frac{14171.1}{28{,}000{,}000}\right)1000 = 1.02 \text{ in.}$$

The use of flat bars for tension members is very apt to be accompanied by some uncertainties: for example, (*a*), unequal intensities of tension due to bars not being straight; (*b*), inconveniences arising from bending of flats in shipment.

In the truss under discussion, if each top chord panel length had been increased 4 in. the diagonals *I J* would have removed the trapezoidal central section and thereby removed the possibility of bending in the central top chord panel due to unsymmetrical loading on the truss. Such a change would also increase slightly the weight of the web system. That the bending stress due to unsymmetrical loading may be considerable, in case such a loading were possible, is shown by the following simple calculation. Assuming a uniformly distributed live load of 20 lb. sq. ft. over one-half of the span, assuming span of 52 ft. and bays of 16 ft., central top chord panel 48 in., a top chord of one 5 H—18.9 having a section modulus of 9.5, the shear in central panel is $16 \times 26 \times 20/4 - 16 \times 2 \times 20/4 = 1920$ lb. and the resulting fiber stress in outermost fiber of top chord is $1920 \times 48/9.5 = 9700$ lb. sq. in. This stress results only from bending. In addition, that due to direct compression also exists. The combination of these two must be kept within safe limits. This suggestion applies only where unsymmetrical loading may occur.

Building Up and Heat Treating Rail Ends

By WALTER CONSTANCE

✦Paper read before the 33rd Annual Meeting, International Acetylene Association, Philadelphia, Pa., November 16, 17, 18, 1932, by Walter Constance, Supervisor of Reclamation, Chesapeake and Ohio Railroad, Barboursville, West Virginia.

AS A railway blacksmith, I first came into contact with gas welding and cutting as early as 1906. By 1909 we had developed the use of generators and had piped gas through the shops.

In the Railway Reclamation Plant where I worked, we tried welding frogs as early as 1914, but had little success because of the lack of suitable rods for this class of work. The cutting torch, however, had become almost indispensable at this plant, as we had to cut much rail for the manufacture of guard rails and frogs.

By 1916 welding rods had been developed which gave better results and, as we had frog repairmen who repaired frogs and switches on line of road, we equipped them with cutting and welding apparatus. Rail ends were built up incidental to these repairs.

Rail ends were welded to considerable extent before the late war, but it was not until the early twenties that rail end welding became a recognized practice on railroads in general. By this time considerable improvement had been made in welding torches and rods had been developed which gave satisfactory results.

There are three ways by which track that rides poorly on account of battered rail ends can be improved. These are by laying new rail, relayed cropped rail or welding the battered joints in track. The latter method is the most economical.

When we had but a limited number of welders, we did only spot welding; that is, welded the joints which were battered the worst, but as the economy of the operation became more apparent welding forces were increased, and now our welding is mostly out of face. The work on our line is programmed and carried out the same as other track work. To show the increase in this work, in 1926 17,717 joints were welded on the road with which I am connected at a cost of $1.52 per joint, and during 1931 147,639 joints were welded at a cost of $0.9135 per joint. All the reduction in cost is not due to improved skill, materials and methods, though they had their part, but is due in part to the fact that we do not let our rail joints get in such bad condition as was once the case. We commence to weld joints now when as little as $^1/_{32}$-in. mash is shown.

When we first started rail end welding, we laid the metal on and avoided hammering the deposited metals as much as possible. We now hammer the added metals while at welding heat. At first new metal was deposited to bring the rail end to the proper surface and contour, but later at the suggestion of representatives of one of the companies interested in the oxyacetylene industry, when the rail ends are battered down or "snake-headed," as we designate them, we began to heat the rail end to a forging heat and drive the head back to shape, and only enough metal added to bring the rail to the proper contour. This saves considerable material and reduces the cost of reconditioning the rail ends.

Recently, as a step forward, these reformed or reconditioned rail ends have been heat treated. This is accomplished by bringing the rail end to the proper heat with the oxyacetylene torch, then quenching with water to a temperature slightly above the boiling point of water. Sufficient heat is then applied to effect a draw, so that a hard and tough structure is obtained.

Most roads depend on the blacksmith flatter to make a finished surface, but some are now using a gasoline operated grinder to obtain the desired surface, and I believe the practice of grinding joints is spreading. However, I am of the opinion that a good track welder can obtain a perfect surface with a flatter using a straight edge as a check. This, of course, does not apply to electric welding, for in that process the rough surface of the deposited metal has to be ground smooth.

Some roads are now heat treating the ends of new rail, but we have not progressed far enough to speak with authority as to the success of the process, although one large system has used this method for four years and claims many good things for the practice.

Our welding gangs are well organized with a foreman and several welders working together, oxygen and acetylene being ordered in large quantities to carry out the programs. One large trunk line is now operating a welding crew with thirty or more welders in the gang. The joints are gas welded, heat treated and ground at a cost of less than one dollar per joint.

Our costs of oxyacetylene welding have been reduced from year to year until the average cost is now well under one dollar per joint.

By the use of the proper welding rod and heat treating, we have been able to produce a reconditioned joint that will materially lengthen the life of the rail.

The railroads owe the acetylene people much in the development of this method of securing greater life from rail.

The Principles of Bronze-Welding

By A. R. LYTLE

✦Paper presented at the September 20, 1932 Meeting, New York Section, American Welding Society, by A. R. Lytle, of Union Carbide and Carbon Research Laboratories, Inc.

THE term "bronze-welding" is understood by the practical welder to refer to the joining of the high melting point metals such as steel, cast iron, nickel and copper, by the use of bronze-weld metal. For many welding applications, bronze-welding offers the advantages of speed, economy and ability to do jobs which might otherwise be difficult or impossible. Although the average welder is familiar with this process and applies it to a considerable extent in his daily work, its fundamentals are probably not as thoroughly appreciated as are the fundamentals of fusion welding. Therefore, it is the purpose of this paper to discuss the general principles of the process and to include the various items of the procedure employed in applying it.

Before describing the process it is believed that a brief discussion of the compositions of bronze-welding rods might be helpful. In the first place, as has been pointed out a number of times, the word "bronze" is not correct as the alloys are really brasses, and practically all bronze-welding rods are composed of about 60 per cent copper and 40 per cent zinc. The reason for this unanimity will be clear in the following discussion.

When zinc is added to copper in increasing amounts, the copper is somewhat strengthened, but its essential physical properties, low strength and high ductility, are not materially altered until over 34 per cent zinc has been added. The alloys containing up to this amount of zinc are what are termed "alpha brasses"; that is, they are an agglomerate of crystals of one type. They can be cold worked very satisfactorily, but are hot short, and their principal use is for tubing and other articles requiring deep drawing. They are quite resistant to various common types of corrosion. Because of their hot shortness and low strength in the as-welded or annealed condition, these alloys are of little value for welding rods. When more than 34 per cent zinc is added, a second, harder constituent called "beta" gradually appears, and, at about 40 per cent zinc, 60 per cent copper, the alloy is made up of about half alpha and half beta. With the introduction of increasing proportions of this beta constituent, the strength of the alloy in the annealed condition increases rapidly while the ductility becomes somewhat lower. At the same time, the hot shortness disappears and the alloys can be hot rolled, forged or welded with complete success. The copper-zinc ratio of 60 to 40 produces the best combination of high tensile strength and ductility, and has, therefore, been used in commercial practice for all alloys of this type. This alloy is known as Muntz metal. In adopting this alloy as the basis for bronze-welding rods, therefore, the welding metallurgist has been able to employ a widely used composition, which gives high strength and good ductility and which, moreover, has considerable strength when hot. In addition, it happens that the freezing range of this alloy is the narrowest of the entire usable copper–zinc system. This is a further advantage from the view-point of the welder, as a quick-freezing alloy is much easier to work with than a slow-freezing one.

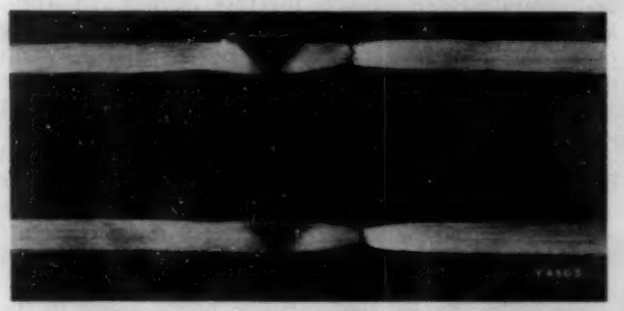

Fig. 1—Photograph of Reinforced and Unreinforced Tensile Coupons Taken from Bonze-Welds on Steel Plate. The fracture in both of these coupons occurred in the plate at a tensile strength of about 52,800 lb. per sq. in. Natural size

Fig. 2—Photograph of Forward and Backward Bends of Bronze Welds on Steel Base Metal. An elongation of 32% in the weld metal was obtained in the forward bend test. In the backward bend test the specimen withstood considerable abuse without failure. Natural size

However, in spite of these excellent physical properties, the straight 60 copper, 40 zinc alloy is almost never used for bronze-welding operations. Most of the welding rods contain about 1 per cent tin. Tin slightly hardens and increases the strength of the metal, but its greatest effect, in so far as the welder is concerned, is on the flowing qualities of the metal during the welding operation. The 60–40 copper-zinc alloy fumes and boils during welding and is a little sluggish in flowing ahead onto the base metal, but tin aids in obtaining the molecular union or tinning which is so necessary for a good joint. Tin also serves as a deoxidizer, preventing in a large measure the formation of zinc oxide within the alloy. The usual bronze-welding rod is composed of these three metals in about the proportions given above. Other metals such as lead, iron and manganese are also present, but these, especially the lead, are maintained as low as is possible in the manufacturing process used. Lead is quite objectionable as it increases porosity and, in general, the quality of the rod varies with the amount of lead present.

Another type of rod known as manganese bronze is used quite extensively for building up wear-resisting surfaces. Practically all these rods contain, in addition to the copper, zinc and tin, as described above, about 1 per cent iron and appreciable amounts of manganese. The presence of iron and tin causes the formation of innumerable small, hard particles called "delta," evenly distributed throughout the bronze matrix. It is the presence of these hard particles which gives to the deposited metal its wear resistance, as the hard particles

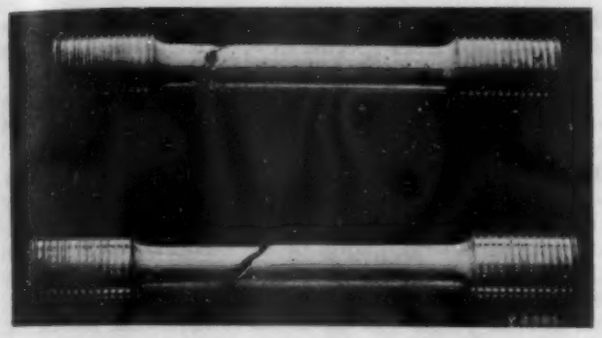

Fig. 3—Photograph of the Tensile Coupons of All-Weld Metal Deposited with the Oxyacetylene Blowpipe. The shorter specimen on the top is composed of manganese bronze-weld metal, and the longer specimen on the bottom is composed of silicon bronze-weld metal. The difference in the length of the specimens is an indication of the value of silicon in increasing the toughness and ductility of the deposited metal. Most of this increase is due to the absence of porosity in the metal. The tensile strength of this silicon bronze was 66,000 lb. per sq. in. with an elongation of 25% in 2 in. The tensile strength of this manganese bronze all-weld metal coupon was 47,000 lb. per sq. in. with 8% elongation in 2 in. Natural size

serve to support the load, thereby saving the matrix itself from excessive wear.

In addition to the above-mentioned types of rods there is also a series of proprietary rods in which silicon, as well as tin, iron and manganese, has been added to the base. This element performs several notable functions when added to bronze-welding rods, which are of value to the welder and which make silicon-containing rods distinctly different from other bronze-welding rods. In the first place, as in steel, silicon functions as a deoxidizer, removing tin, copper and zinc oxides and replacing them with silicon dioxide which floats readily to the surface of the melted weld metal. This silica unites readily with the usual bronze-welding fluxes. In the second place, silicon causes any gases that are dissolved when the metal is at high temperature to be retained in solution during solidification instead of being thrown out of solution as occurs when silicon-free alloys solidify. The result of this is that the deposited metal is free from porosity and blowholes and, as a consequence, has greatly increased strength and toughness. The third advantage of adding silicon to bronze-welding alloys, and this is of special importance to the welder, is that, due to the presence of the film of slag over the surface of the molten puddle, the fuming and oxidation of zinc are greatly retarded. In fact, it is possible by adding sufficient silicon to prevent zinc oxide fuming almost completely. This reduction in zinc fuming is a great benefit to the comfort and health of the welder.

Not much information has been published on the theory that underlies the fact that brass alloys will flow onto base metals of a higher melting point and for a joint that has very good strength and ductility. However, we are well acquainted with the general conditions that must be met in order to obtain the most favorable results. First, it is essential that the base metal be clean and free from foreign matter that might interfere with or prevent the capillary flow or wetting of the bronze-weld metal. With the usual ferrous and non-ferrous metals such as steel, copper and nickel, it is necessary only that the base metal be free from oil, grease or scale. This can usually be accomplished by grinding. However, even after grinding and cleaning, some metals such as aluminum bronzes and stainless steels retain a superficial coating of oxide that prevents the bronze-weld metal from coming into intimate contact with the base metal. If this coating can be removed by chemical or abrasive means and the weld metal brought in contact with it before the coating is reformed, then the bronze-welding operation can be conducted satisfactorily. This removal of the coating is sometimes accomplished by the use of especially active fluxes.

Although bronze-weld metal flows freely onto practically all cast iron if the surface is properly ground and free from dirt, there will be an occasional section of cast iron on which the bronze-weld metal flows only with difficulty. It will usually be found, however, that either the surface has not been cleaned or ground thoroughly enough so that all scale and oxide are re noved, the cast iron has been seriously oxidized in service or it is a poor grade casting.

After the base metal has been properly prepared, it is then heated by means of the oxyacetylene flame to the temperatures at which the bronze-weld metal will flow onto it. This temperature is about 900° C., which is about 20° above the melting point of the brass alloy. Almost always a flux is used during this welding operation. The purpose of this flux is to clean the base metal of the oxide that is formed on it ahead of the welding zone, due to the effect of atmospheric oxygen on the heated base metal, and also to dissolve the oxides formed during the bronze-welding operation. These may be either silicon, tin, copper or zinc oxides. The presence of excessive amounts of any of these would hamper the welding operation considerably and lead to the formation of either a poor joint or unsound weld metal. Consequently, the use of a high quality bronze-welding flux is essential for obtaining the best results.

An additional aid in obtaining consistently high strength joints is the use of the proper flame adjustment. Bronze-welding cannot be satisfactorily conducted with the excess acetylene flame due to the effect of the carbon in causing porosity in the deposited metal and in depositing a film over the surface of the base metal ahead of the weld, hindering the tinning operation. A neutral flame is satisfactory for bronze-welding and is used by a large number of welders, but laboratory tests have shown that a slightly oxidizing flame is much more reliable and produces welds in which the adhesion between the weld and base metals is consistently better and which has uniformly higher strength and ductility.

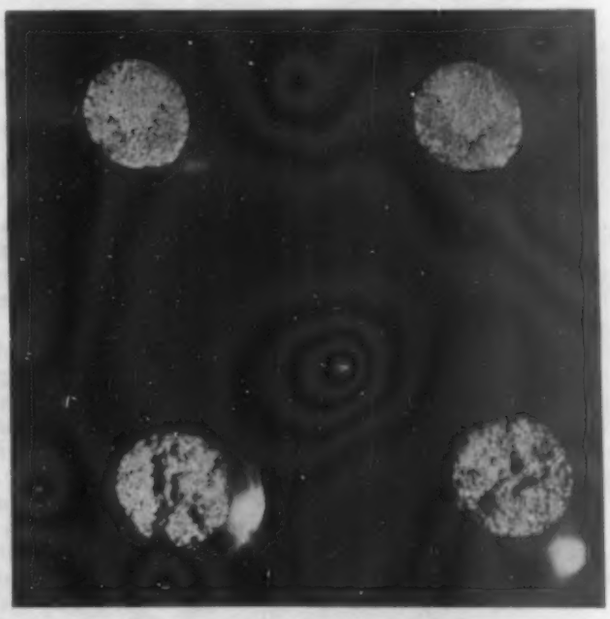

Fig. 4—Photograph of the Fractures of the Tensile Coupons in Fig. 3. These show a certain amount of porosity in the manganese bronze deposited metal and complete freedom from porosity in the silicon bronze deposit shown at the top of the photograph. Natural size

Fig. 5—Photomicrograph Showing the Structure of Alpha Brass Base Metal. All the grains are of the same composition. The dark areas are globules of lead, added to improve the machining properties of the alloy. × 100

It appears that it is especially desirable to avoid traces of excess acetylene that occur even in an apparently neutral flame. A slight but positive excess oxygen flame adjustment is sufficient for the purpose. It is believed that the proper flame adjustment is one of the principal factors in securing consistently high physical properties.

Before describing the physical properties of the bronze-welded joint, it is believed timely to discuss two characteristics which affect certain applications of bronze-welding.

One of these has been observed in cases where it has been necessary to re-apply bronze-weld metal a number of times on a steel surface, such as a wearing surface, which is subjected to severe alternating and repeated stresses. Under such conditions, there is a possibility that bronze-weld metal may penetrate between the grains of steel base metal to an extent which may cause cracking of the steel. It is, therefore, the recommendation of experienced welding engineers that bronze-welding with any of the rods previously described should be applied only once on steel for such services as are subjected to severe alternating tension and compression stresses. It is important to emphasize that this penetration does not occur when bronze-welding is applied to cast iron and that, consequently, bronze can be re-applied as often as desired to cast iron.

The second characteristic is the relatively low strength of brass at elevated temperatures. Brasses of the types described above begin to lose their strength at temperatures above 500° F. This fact should be kept in mind when considering the use of bronze-welding for parts which may be subjected to high temperatures in service.

Of course, it is upon high strength, ductility and general reliability that the extensive use of the bronze-welding process is due. However, it is believed that the average welding engineer does not appreciate the high strengths and ductility that can be obtained when the proper procedure and welding rods are used for the operation. To secure these data, a number of tests were made to determine the conditions under which the best combination of strength and ductility in the bronze-welded joint would be obtained, and in these tests the composition of the rod, the preparation of the base metal and the adjustment of the flames were studied. The results of these tests are given in the following table. As it was learned early in the investigation that the excess oxygen flame should be employed, all the data in these tables were obtained from specimens on which this flame was used.

The first physical property of importance is the tensile strength. When the usual copper-zinc-tin bronze rod is used for welding steel, a tensile strength of about 41,000 lb. per sq. in. on unreinforced coupons can be readily and consistently obtained. The fracture is usually through the weld metal and shows some porosity, although the general quality of the metal is good. When the manganese bronze rods are used, the strength may be somewhat greater, averaging about 46,000 lb. per sq. in., but the porosity in the metal is somewhat increased. However, rods of essentially the same composition as the two former rods, but containing silicon, have an average tensile strength well over 53,000 lb. per sq. in., and with the usual grade of tank plate which ordinarily has an average tensile strength of 52,000 lb. per sq. in., practically every fracture should occur in the base metal. Sections taken through the weld metal with this rod show almost complete absence of porosity, which is attributable to the effect of silicon in causing the gases to be held in solution. It might be pointed out that a number of welds have been made in which the tensile strength of the bronze-welded joint has been consistently over 65,000 lb. per sq. in.

It is obvious, of course, that in the bronze-welding operation the strength of the joint is dependent on three components: the weld metal, the base metal and the bond between the two. Therefore, in any efforts made to increase the joint strength, the weakest of the components, which is the bond, must be taken into consideration. The presence of silicon has been found to increase the strength of the weld metal considerably, but the combination of silicon in the welding rod with the use of a slightly excess oxygen flame has increased the strength of the welded joint so that it is readily possible to obtain a uniform tensile strength of 55,000 lb. per sq. in. and over. Even under these conditions the bond strength is the limiting factor, as is shown by the results of the tensile tests of all-weld metal deposits, these values being considerably higher than those obtained with the welded joints.

Further information on the value of the bronze-welding method is given in the forward and backward bend tests. In both of these types of tests the results depend to a great extent on the amount of porosity in the

Fig. 6—Photomicrograph Showing the Welded Joint between Alpha Brass Base Metal on the Right and the Alpha Plus Beta Weld Metal. This structure of the weld metal is typical of that obtained with bronze-welding rods. × 100

Type of Coupon	Alloy	Lb. per Sq. In. Yield Point	Lb. per Sq. In. Ultimate Strength	% Elongation Tensile Test	% Elongation Bend Test	Brinell
All-weld metal as deposited	Copper-tin-zinc	13,500	46,500	25.0	...	68–72
	Manganese bronze	17,000	48,000	8.0	...	74–79
	Silicon bronze	21,000	63,500	23.0	...	91–101
Bronze-welded steel coupons	Copper-tin-zinc	40,000	41,000*	..	10–12	....
	Manganese bronze	41,100	46,500*	..	10–12	....
	Silicon bronze	41,100	52,700**	..	25–35	....

* All average of 5 coupons. Reinforcement removed from all specimens.
** All 5 coupons broke in the plate.

weld metal. Good quality welds with the copper-zinc-tin alloys may have relatively high ductility as the metal is inherently ductile, but manganese bronze welds usually are poor in the bend test. Welds with the silicon bronze should bend flat if the welds have been made properly and should show high elongation in the weld metal.

For building up wear-resisting surfaces, the manganese and silicon bronzes have proved invaluable in innumerable applications. This property of resisting wear is due to the greater hardness of the metal as compared with usual brass and to the presence of microscopic constituents that are very hard. These act as bearing points to support the load, thus saving the rest of the alloy from excessive wear. The copper-tin-zinc composition does not have this hard constituent and so is not suitable for bearing surfaces.

Summary

This paper has outlined the general characteristics of bronze-welding rods and has described the procedures that should be followed in order to obtain the maximum benefits from the process. Care has also been taken to point out the limitations of the process so that it will not be applied for construction for which it is basically unsuited. In addition, data have been presented to show the high strength and ductility that can be secured, and it has been pointed out that the wear resistance is very satisfactory. From this discussion the great value of the process as a construction and repair method will be obvious.

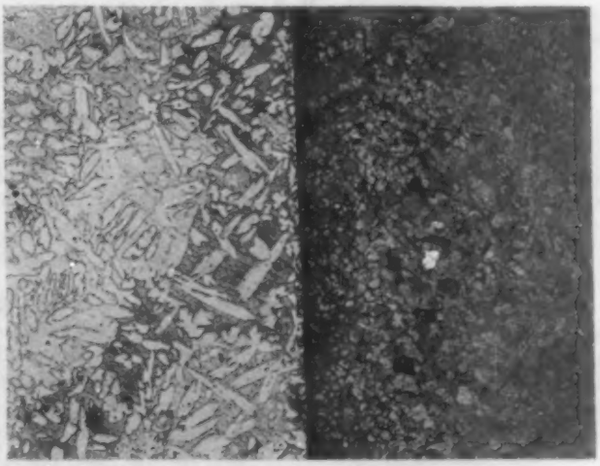

Fig. 8—Photomicrograph of the Bronze-Welded Joint on Steel Base Metal. This magnification reveals no intermingling of constituents in this joint as there is in the joint between the alpha brass and the bronze-weld metal. Nevertheless this joint has high strength as indicated in the tensile and bend tests. × 100

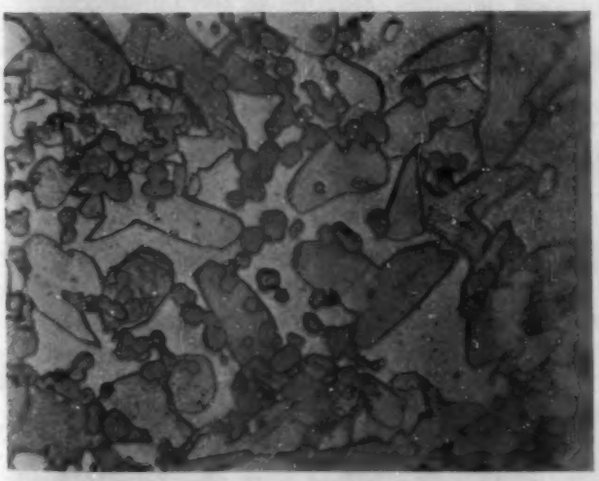

Fig. 7—Photomicrograph Showing the Delta Constituent in the Manganese Bronze-Weld Metal. This constituent is present in the form of the round, grayish particles in the ground mass. These particles are considerably harder than the surrounding metal and serve to carry the load. × 500

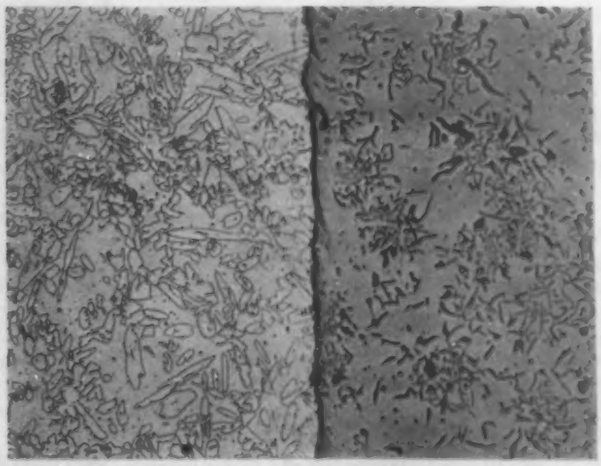

Fig. 9—Photomicrograph of a Bronze-Welded Joint on Cast Iron. As in steel, no intermingling of the alloys can be observed. Nevertheless this joint has high strength and ductility. × 100

Fundamental Research Problems in Welding

✦Compiled by the Fundamental Research Committee of the American Bureau of Welding.

The Bureau

THE BUREAU is a joint research Board affiliated with the AMERICAN WELDING SOCIETY and the NATIONAL RESEARCH COUNCIL. The Board is composed of representatives from the AMERICAN WELDING SOCIETY and from some twenty other interested engineering and scientific bodies. It has concerned itself with the promotion and coordination of research in the welding field.

Applied Investigations

Although the possibilities of welding were generally recognized a number of years ago, progress in various applications was retarded because of lack of fundamental design data and underlying fundamental knowledge on many important factors. Moreover, there was a lack of standardization as to procedures with a consequent irregularity of the resultant product. A lack of familiarity with the various welding processes on the part of regulatory bodies and engineers in general was also a contributing factor to the retardation of progress.

It was quite natural, therefore, that the first investigations of the Bureau should deal primarily with such practical problems as training of operators, standard tests for welds, welding wire specifications, technique of welding and investigations on rail joints, pressure vessels and structural steel. These investigations have brought about a uniformity of product and a decided improvement in the quality of the product. As a result of the satisfactory progress made by the welding industry, partly due to the investigations mentioned above, welding under proper restrictions is extensively used in fabricating machine parts, is permitted for use with all pressure vessels and has been adopted in the building codes of some 125 cities and municipalities.

Fundamental Researches

With the growing use of welding there is a greater need than ever before for investigations of the fundamentals. The "reasons why" of things are rarely understood and none too often sought. Again, in other instances there is a lack of fundamental design data. To meet the present needs and to foster researches of this kind, the Fundamental Research Committee of the American Bureau of Welding has been organized under the chairmanship of Mr. H. M. Hobart, Consulting Engineer of the General Electric Company. The opportunities for real service to the industry in this work are almost limitless and the possibilities of securing results of value are extremely great. Some of these problems can be best handled by the university. Moreover, in this way the teaching staff and students will become familiar with the recent developments in welding practice.

The Fundamental Research Committee comprises representative scientists of industry and also professors interested in the conduct of fundamental research work in welding. In particular, the Committee endeavors to stimulate interest in these investigations on the part of various universities. A list of problems needing investigation is compiled each year and distributed to selected universities. These universities are allowed a free hand in the selection of problems for study. The Bureau assists, when called upon, in the formulation of problems undertaken for study.

Procedure

The first step is to gain a thorough knowledge of what has already been done. The Bureau assists in furnishing selected references to published information both in this country and abroad. If requested, the Bureau assists also in indicating possible lines of attack and in supplying specimens as may be needed, made up under the conditions specified by the laboratory. Occasions to be of assistance in all sorts of ways are constantly arising.

In brief, the function of the Committee is to expedite progress and stimulate activity without in any way assuming authority or dictatorship.

In the past, the members of the Committee have assembled once a year at the time of the Fall Meeting of the SOCIETY. To make these conferences a success the Committee has raised a small sum of money to defray the railroad and pullman expenses of those professors who could not otherwise have their expenses met. Reports of investigators are published in the JOURNAL OF THE AMERICAN WELDING SOCIETY, with or without presentation before some meeting of the SOCIETY. In a few instances publication has been in other journals and presentation before other societies.

Local Branches of Committee

To expedite progress and to hold more frequent meetings of local groups interested in fundamental research in welding and to permit more active cooperation of local industries, branches of the Fundamental Research Committee have been formed in Boston, Prof. J. P. Walsted, Mass. Inst. of Tech., Chairman; New York, Mr. J. M. Keir, Union Carbide & Carbon Research Lab., Chairman; and Pittsburgh, Mr. C. H. Jennings of the Westinghouse Electric & Mfg. Co., Chairman. Others will be formed when found desirable.

List of Fundamental Research Problems in Welding

The remarks following the titles of the problems were contributed by various specialists.

Group A—Investigations Involving Physical Tests

In addition to the problems listed below many of the investigations included in the other groups are dependent upon physical tests.

1. Relation of Ductility to Other Physical Properties.

This problem, to be worked out completely, presumably would require impact and fatigue tests. Ductility does not influence static tensile strength appreciably, if at all, but has marked effect on impact and fatigue. Sufficient fatigue specimens should be provided for any one set of conditions so that endurance limit may be determined.

2. Impact Resistance of Welded Joints.

The question of the shape of specimen for impact test is the most important for this investigation. The specimens will be different for different types of joints. For any one type of weld the effect of welding procedure should be studied. At the present time there is no

standard unit basis of comparison for impact strength. The result of the test will depend upon whether the impact is applied transversely with bar notched or unnotched, or in tension with weld reinforcement, if any, left on or removed. In the case of a fillet weld, obviously the result of the test will depend upon the direction of application of impact and the amount of weld tested in the specimen.

3. Fatigue Tests on Weld Metal and Butt and Fillet Welds.

(Much work has been done on welds made on low-carbon steel, therefore it is desirable that this work include alloy steels and non-ferrous metals.)

Although considerable work may have been done on fatigue testing of weld metal and butt welds, certainly it cannot be said that sufficient work of this nature has been done with fillet welds on carbon steel. If such results have been obtained they are not widely known in the welding industry. In any case the data from fatigue tests of welds are still far too incomplete for the needs of the industry. In many cases the laboratory results cannot be practically applied because of some test condition used which does not occur in actual practice. Fatigue tests of welds in the "as welded" state seem to be desirable. Similar tests on alloy steels and non-ferrous metals are also desirable. Most important, at present, is the fatigue strength of fillet welds.

4. Study of the Effect of Specimen Design on the Tensile Properties of Butt Welds.

(This work should be confined to specimens so prepared as to cause failure to occur in the weld.)

Work on this problem should be directed toward the development of a reduced section tensile specimen that will give consistent and reliable results that are comparable with those obtained from parent metals with standard specimens. To accomplish this end it is desirable to investigate each specimen design by using several grades of welding because the ductility of the weld has an important effect upon the results obtained.

5. Corrosion Fatigue Tests on Butt Welds in Weld Metal.

This problem is of the standard corrosion fatigue type and needs little explanation. Complete endurance curves should be made in every case.

6. Relation between Density and Ultimate Strength of Weld Metal.

This problem presumably should include impact and fatigue tests as well as tensile. In connection with density of weld metal or its opposite, "porosity," the problem of rating the weld on the basis of "density" or "porosity" would be much simplified if some standard basis of rating could be established whereby the welds could be compared intelligently. The X-ray is suggested as the most accurate method of determining the amount, type and location of porosity and of other defects in the weld.

While at Watertown Arsenal Dr. H. H. Lester, X-ray metallurgist, and other collaborators, prepared a tentative classification for butt welds by which they could be rated on the basis of type, amount and location of porosity as determined by X-ray examination. This system was used to some extent for fillet welds. The work was not carried far enough to correlate physical test results with the X-ray films. Work of this sort should be done as noted in Group C (10).

7. Relation between Ductility Values as Obtained from Tensile and Bend Specimens.

It has long been the practice to judge ductility as indicated by the deformation of a sample that has been tested in tension. Since many field tests have to be made on samples taken from welded joints, it is not always convenient to make the tensile test. Within the last few years, there has been developed a method of measuring ductility by observing the per cent elongation in the outer fibers of a sample that has been bent according to a certain simple procedure.

This bending method of measuring ductility nearly always gives much higher results than testing the same piece in tension. There has been no serious effort to establish the ratio between the two tests or to determine if there is a definite relationship between the tests of similar samples that have been subjected to these different tests, the samples being made by different methods of welding and on different industrial metals. This bend test has now been standardized, is used in the pressure vessel code and seems in a fair way to have universal recognition.

In order to make a conclusive report on this subject, a relatively wide variety of bend tests on welded samples should be made covering various plate thicknesses of different industrial metals, and the welds should be made by various processes. Such experiments should provide enough information to prepare an analytical treatment bearing upon the usefulness of this test and its relationship to other methods of ductility testing.

8. High Temperature Tests (long and short time tests) on Weld Metal and Welded Joints.

This work is of great importance in connection with pressure vessel work where the temperatures are high. In making long time creep tests it is important to know the relative effects produced by the weld and the base metal. Two possible methods of separating these variables are: (1) vary the ratio of weld metal (width of joint) and base metal included in the gage length; (2) study separately weld metal and base metal specimens.

9. Quantitative Studies of the Internal Stresses Caused by Welding Operation.

Probably the best way to attack this problem is to design special tensile and fatigue specimens which will contain known amounts of residual stress when welded. Varying the initial residual stresses and noting their effect upon the results of the tensile and fatigue tests will give valuable information on their effect upon welded structures.

10. Study the effect of heat of welding on hard drawn copper with reference to tensile and fatigue properties and possibilities of cold working to restore original strength.

When welding hard drawn copper the heat of welding will anneal the section adjacent to the joint. It is desirable, therefore, to know how great this annealing effect is and whether or not the joint strength can be raised by cold working or hammering.

There is some doubt in our minds as to there being a wide usefulness to a solution of this problem. Probably the greatest field for the welding of copper is in the electrical field where the strength of the metal used is of secondary importance to the electrical conductance of the material at and near the joint. There are relatively few applications where it would be necessary to consider, at a welded joint, the additional strength obtained by having all the material in a work hardened condition. However, we shall outline the problem as we believe it should be considered.

At the present time there are two principal types of copper available on the market. The old standard type is of the oxidized form and contains a considerable amount of cuprous oxide. The other type which has come greatly to the fore in recent years is deoxidized copper. This material generally has silicon or other deoxidizing material present in a sufficiently small quantity to insure the absence of oxidized material and not

to greatly detract from its property of electrical conductance.

The oxidized material, when subjected to the heat of welding, permits a rearrangement of the cuprous oxide around the grain boundaries and greatly reduces the physical strength of the heat-affected part of the base metal. In those cases where high strength is required, it is believed that the only way in which the original strength can be restored is by cold working. In order to study this particular feature, the program should be started by taking portions of oxidized plate and annealing these to a range of temperatures all the way from about 1000° C. down to a point at which the experimenter has determined that the heat effect has no weakening influence. These samples might be prepared for tensile and fatigue tests, if considered necessary, in order to provide the basic facts pertaining to this effect on oxidized copper.

No record is known in which the above data are contained, and it would be almost necessary to carry out these experiments.

The next part of the investigation would be an effort to seek a practical solution to overcome this weakening of the metal. Welds could be made in this same type of plate and then be subjected to cold working, which could be carried out by ordinary cold rolling means to determine how efficient this procedure is for restoring the original strength of the material. There would be some physical difficulty in providing additional material over the heat-affected region where the cold working would reduce the effective section and, from a strictly practical view-point, this matter would have to be considered.

No figures are available pertaining to the percentage loss in strength resulting from the welding heat effect in deoxidized copper. There is, however, no cuprous oxide to be considered and the strength loss would occur in this material strictly as a rearrangement of the cold, previously worked crystals. A series of experiments similar to those on the oxidized plate should be carried out in which annealing at various temperatures followed by cold working should be made. This would give a view of the effect of the heat treatment and the next step would be to make welds with the special type of deoxidized rod which is available on the market for welding this material.

11. The new boiler code of the A. S. M. E. has placed a lower limit of 20% tensile elongation and 30% for bend test elongation for the highest quality of weld metal in Class 1 pressure vessels. There is no conclusive information available that shows the need of this highly ductile material in a welded joint, and the limit of safety has merely been set to leave the most comfortable feeling in the minds of the code designers, with the full knowledge that welding is a new industry and has to be carefully protected. This high limit of ductility is obtainable only by the very highest type of factory practice, and a good portion of the industry is inclined to look upon it as providing a monopoly to certain manufacturers.

The question naturally arises whether this is an economic waste, and whether this limit of ductility may be decreased without affecting safety. The investigation proposed is to develop and carry out carte blanche a series of tests that will provide positive information on this much debated question.

GENERAL NOTE: There seems to be a general tendency in physical testing of welds to avoid impact and fatigue tests probably because of the time and expense involved in making specimens and tests. In many cases test specimens are made up blindly, i.e., without using the X-ray or some other non-destructive test before machining the specimens to determine the internal conditions of the weld. If such a preliminary examination could be made it would seem that considerable time and expense could be saved and the results of the tests would be more valuable.

Group B—Involving Considerable Metallurgical Experience

(See other Groups, particularly Group D)

1. Relationship of Nitride Needles and Physical Properties.

Nitride needles are considered to have an important effect upon the ultimate strength and the ductility of welds. (Much evidence in support of this fact has already been obtained.) Consequently, it would be valuable to have a direct correlation between nitrogen content, ultimate strength and ductility.

This problem is important because of the increased use of the electric arc welding process. There is no doubt that nitrogen is somewhat harmful but there are also some beneficial influences due to the presence of this element in weld metal.

The problem involves, first of all, a comprehensive review of all literature on the subject of nitrogen in iron and steel, its cause, factors influencing the extent of nitrogen absorption and physical properties modified by such absorption. It involves also a review of all literature on nitrogen in weld metal with methods of control.

The investigation in the laboratories will start with methods of controlling the amount of nitrogen absorbed in electric arc welding. This part of the investigation is, by itself, very important to the industry.

Having developed methods of controlling the amounts of nitrogen, the investigation will then deal with the properties of weld metal with varying amounts of nitrogen.

2. Effect of Heat of Welding on the Adjacent Materials with Particular Reference to Various Alloy Materials.

Nearly every type of plain carbon and alloy steel has been welded with more or less success. The results obtained, however, are not always entirely satisfactory because of the change produced by the heat of welding in the base metal adjacent to the weld.

When welding chrome nickel steels there is danger of carbide precipitation which reduces the resistance of the affected metal corrosion but does not affect its strength. Welding certain chrome alloy steels causes grain growth which affects the strength of the metal. When welding manganese steels there is danger of burning out some of the manganese and producing a hard brittle zone. The heat produced in welding malleable iron sometimes reduces the parts adjacent to the weld back to cast iron. When welding high-carbon steels some of the carbon may be burnt out, thereby reducing the strength of the joint.

In studying the effect of welding heat on the metal adjacent to the weld, two objectives should be kept in mind: first, find out what effect is produced; second, determine how these effects can be corrected either by changing the welding procedure or by subsequent treatment.

3. Effect of Flame Cutting as Compared with Other Methods of Cutting and Shearing on the Properties of Welds Deposited in Various Compositions of Steel.

4. The Technique of Hardening Welds by Carburizing and Nitriding.

5. The Use of Oxyacetylene Flame for Local Heat

Treatment. Depth and Area of Hardened Zone with Various Thicknesses of Material in Spot Hardening.

(*a*) Types of steel.
(*b*) Effect of air hardening.
(*c*) Effect of water hardening.

Repeat for straight line hardening and also for closed circle heat treatment, making for the latter a study of the end effect and general technique.

6. Effect of Annealing in Hydrogen Atmosphere on the Physical Properties of Welds.

There are many investigators who believe that hydrogen annealing will not be beneficial in improving the quality of welded joints. This is based upon the fact that hydrogen only penetrates metals at a very slow rate and would not be of great commercial usefulness.

To settle this point a series of annealing treatments imposed upon welded samples, made by different processes and in different materials, should be carried out. The ordinary type of tensile and bend tests should be conducted and impact tests should be made on samples having weld metal across their middle. It might suffice to hydrogen anneal the whole solid plate at the most favorable annealing temperature, this plate being then cut up into the samples above suggested. On the other hand, the investigator might consider it necessary to hydrogen anneal some of the samples after cutting from the plate. This would be a matter for the investigator to decide, depending upon the results to be obtained.

7. Study of Systems. The study of the systems: Fe–FeO; Fe–MnO; Fe–N–C; Fe–FeO–N; Fe–FeO–C, N should be of considerable interest to the metallurgy of welds.

8. Effect of Various Alloying Elements in Steel Plate on Density of Weld Deposit.

Items such as nickel, manganese, silicon, chromium, vanadium, etc., should be considered, and combinations of them.

Group C—Problems in Physics

1. Laws Governing Magnetic Disturbances in Arc Welding and How the Latter May be Overcome.

One of the greatest difficulties encountered in arc welding is magnetic (arc) blow. Although a great deal has been done in connection with the control of arc blow, investigators are still far from the solution of the problem. This problem requires investigating into the fundamentals of magnetism and the theory of the arc.

Library Research will be of considerable value in connection with this problem.

2. Magnetic Characteristics of Various Types of Welded Joints for Use in Electrical Machines.

3. Metal Transferred in Different Positions during Arc Welding.

NOTE: Dr. Dushman states: "I have seen some experiments on inverted welding in which, apparently, the iron was transported from the welding rod to the welded material as a vapor. I could not see any evidence of transport of iron by sputtering and there was certainly no transport by actual contact of the fused end of the rod. Now, by comparing the amount of material transported under those conditions, for a given current density at the cathode, with the amount transported when the welding is carried out at the same current density in the usual manner, it should be possible to obtain some idea regarding the relative amount of iron transferred by evaporation and mechanical sputtering or fusion."

Mr. Hobart states: "It would be instructive to have oscillograms for flat welding and inverted welding with the same volts and amperes in both cases and all other conditions the same. For flat welding we should presumably find several short circuits per second which some would ascribe to the metal being transferred in drops, one drop per short circuit. For inverted welding these short circuits might be absent.

"Many other comparisons could be made using this same general line of attack."

Prof. G. E. Doan states that some investigators attribute the upward transfer of metal to the "pinch effect." Another investigator has shown oscillograph records indicating short circuits in overhead welding caused by transfer of metal in globules. Others attribute transfer to explosion of gases in ordinary electrodes.

4. Comparative Arc Behavior with Iron Electrode in Argon, Nitrogen and Air with Arc Formed by Electrode Containing Slag and Oxide.

GENERAL NOTE: From the standpoint of arc behavior the question of melting rates of various electrode materials seems to be of some interest. A study of the effect of arc conditions and various elements in the electrode on the melting rate may lead to some definite conclusions regarding arc phenomena. This study could be made in conjunction with Problems (6) and (7).

There is also the question of the effect on arcing characteristics of various elements on the surface of the electrode and the effect of these elements on the melting rate of the electrode. This problem is suggested as an elaboration of (4).

NOTE: Dr. Dushman states: "There is distinct evidence that the stability of the arc depends upon the presence of small amounts of oxide on the surface of the cathode. For this reason, I would like to see experiments in which attempts are made to carry out welding with electrodes which are thoroughly free from oxide and, furthermore, if possible, these experiments should be carried out in an atmosphere of argon in order to avoid oxidation."

5. Effect of Electrode Containing Cobalt and Nickel on Behavior of Arc. (See Note above.)

It would seem desirable to include also other alloying elements such as chromium, manganese, vanadium, tungsten, etc., to determine their effect on arcing characteristics of the electrode.

6. Volt-Ampere Characteristic of an Iron Arc as a Function of Arc Length.

7. Motion Pictures of Metal Transference in the Arc.

Motion pictures of metal transfer are of extreme value in connection with the theory of the arc. Such pictures must be taken at very high speeds in order to be of real value. Consequently this work would require expensive and special equipment. Motion picture studies of arc welding in the vertical and horizontal planes would throw new light on these subjects.

8. Calorimetric Study of Carbon and Metal Arcs.

This study would be of great practical value if the heating effect of various arc conditions on the material being welded could be determined quantitatively with reference to the amount of energy used. Such results might lead to methods of predetermining amounts of expansion and contraction by mathematical analysis.

9. Temperatures of the D.C. and A.C. Iron Arcs in Air and Other Gases.

10. Non-Destructive Tests of Welds.

Correlation between X-ray photographs and the actual strength of welds.

Further study of the use of gamma rays for weld examination.

Investigation of the vibration method of testing the soundness of welded joints.

Investigation of electrical and magnetic methods of weld testing with particular reference to fillet welds.

11. Temperature of Oxyhydrogen-Carbon Monoxide Flame with Various Ratios.

12. X-ray Study of Crystal Structure of Welds.

The application of the X-ray diffraction methods to the study of welds covers a wide range of problems. The first group involves the determination of the atomic arrangement in the weld metal and an accurate measurement of atomic spacings. This information leads to conclusions about the way in which various elements occur in the weld metal, that is, as solid solutions or in the form of compounds and, as far as is possible, the rôle which each plays in determining the physical properties of the weld metal. The second group of problems has to do with the important effect of grain distortion upon the properties of weld metal. The paper, "On the X-ray Determination of Stress in Welds," published in the Sept. 1932 issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY, gives a general picture of the problems of this group and points out that there is much to be done in this field.

13. Temperature of Oxyacetylene Flame over All Possible Gas Ratios.

The oxyacetylene flame as used for welding purposes, requires a slightly greater volume of oxygen than acetylene. Since acetylene requires $2^1/_2$ volumes of oxygen for its complete combustion, the balance of the oxygen must be obtained from the atmosphere. This oxygen obtained from the atmosphere entrains with it four volumes of nitrogen that must be raised to the flame temperature and the latter, on account of its chemical inactivity, acts to cool the outer portion of the flame.

The thermal efficiency of welding quite conceivably could be greatly increased if a more efficient flame were possible and the acetylene industry would be greatly benefited by a knowledge of the effect on the flame temperature and chemical composition of varying the oxygen to acetylene ratio from the lowest possible to the maximum theoretical amount. It is possible that by mathematical treatment the flame temperatures with these various gas ratios could be predicted, and this problem is suggested as a line of research.

14. Temperature of the Oxyacetylene Flame for the Same Gas Ratios Mentioned in No. 13.

This problem is suggested for laboratory experiments in order to act as a check on the calculations obtained under Problem No. 13. The purpose in carrying out these problems in a theoretical and also in an experimental fashion is to give a clearer insight into the behavior of the oxyacetylene flame and to help reconcile differences that will undoubtedly arise between the experimental and theoretical results. By proper consideration and analytical treatment of the results in these two problems there would be provided valuable information not now available.

15. Economy of Heat Delivery from an Oxyacetylene Flame into a Steel Plate.

Presumably the heat transfer from the welding flame to a metallic surface is largely by radiation and conduction. Because of this, the total heat delivered into a plate during a welding operation is a relatively small percentage of the total flame energy and this inefficiency might be considered somewhat of an economic waste. If experiments could be initiated which would show definitely a means for substantial improvement, the whole industry would be very greatly benefited.

Generally speaking, the rate of heat delivery into a plate at room temperature is quite high but, as the temperature of the plate increases, the efficiency of heat transfer decreases as the temperature gradient between the plate and the flame decreases. It is, then, at the higher range of temperature, namely, 1200° to 1300° C., that the greatest inefficiency exists. The experiments, then, would naturally lead to a measure of heat input at high temperatures and with a wide range of gas ratios.

16. Spectroscope Examination of the Oxyacetylene Flame.

When acetylene is oxidized in the oxyacetylene flame, the reaction probably occurs in stages. The first stage may be the formation of carbon monoxide and incandescent particles of carbon, with possibly a very small quantity of carbon dioxide. These products of combustion are probably generated around the boundary of the inner cone. These gas reactions in the flame are of the reversible type and they can be carried to complete oxidation only after their temperature has been lowered by radiation and expansion such as occur in the outer flame envelope.

Hitherto, there has been no really conclusive data to indicate the nature of these reactions or their relative importance at the different stages. Substantial information on these points might be obtained by an exploratory study of the different regions in the welding flame with the aid of the spectroscope. The experiments should be carried out on the standard oxyacetylene flame as it is now used industrially, and also on flames having a wide variation of gas ratios. (See Problems (13) and (14).)

The information obtained in this proposed research might be used in conjunction with the researches mentioned under No. 13 and No. 14 to build up knowledge for increasing the thermal efficiency of the oxyacetylene flame.

Group D—Problems Involving Welding Procedure

GENERAL NOTE: Apart from proprietary methods there is much to be done on both gas and arc welding, such as the effect of layer welding, of fore and backhand welding for gas, as well as up and down welding vertically by the arc. In gas welding non-ferrous alloys, excess oxygen and also excess acetylene should be tried. A considerable program could be worked out and the reports in some cases would require metallographic work as well as physical tests.

Many opinions exist in regard to different methods and much fragmentary information is available but it requires being placed upon a completely statistical basis.

1. Effect of Method of Making Gas and Arc Welds on Ductility.

2. Effect of Peening on Quality of Welds.

The chief value of a study of this problem seems to be that some standard method of peening might be established. The question is usually, "How much peening to do, how to do it and what the effect should be." Too much peening can easily be more serious than no peening at all. Just where the limit is for best results is not known.

Peening has been used quite extensively in the electric arc welding industry to improve the quality of the deposited metal. Apparently it has the effect of relieving strain and giving a more reliable joint. There is some statistical information available in the trade journals and institutional records on the effect of this treatment, but it would be worth while to collect this information with the idea of presenting a comprehensive report which would cover the field more fully.

It is believed that the study should be carried out on welded plates of various thicknesses and of different materials. Also various methods of making the welds and varying amounts of peening at different stages of the welding operation should be used. The investigator should devise some strain gage method for determining

the amount of benefit obtained from peening, and possibly some reliance should be placed upon the standard physical tests.

In addition to mechanical tests, micrographs should be taken to make a comparative study of welds with and without peening and with peening under different conditions and to different extents.

Mr. W. Spraragen states that the matter of peening of welds has been under discussion for many years. Some look upon it favorably and others do not. The matter received favorable consideration in connection with the relief of residual stresses in welds, particularly in the welding of heavy parts. Each layer was peened carefully and when properly done has apparently produced good results. Others feel that peening of welds if improperly done might actually do harm in starting initial cracks. They state that there are so many variables involved in peening, such as temperature, weight of hammer, type of hammer, frequency and size of blows, etc. Literature indicates that peening has been found very useful in preventing locked-up stresses and distortions in cast iron welding, manganese welding, the welding of other sections and pressure vessel welding referred to above.

The subject is closely related with residual stresses which is a complicated problem in itself. The effect upon peening of welds with different layers and different thicknesses of material as well as with covered and bare wire and by gas welding should be studied.

Whatever peening is done should be done in such a way that the exact conditions can be duplicated. Perhaps an air hammer with a definite air pressure might be utilized. Some tests would have to be made to determine whether the blows delivered from such a device were fairly uniform.

Mr. H. M. Hobart: "As one of several ways for releasing locked-up stresses and for improving in general the quality of the metal, peening should be considered. It should be applied (preferably with a pneumatic hammer) right after the weld has been completed and while the metal is still very hot. This has long been known to be a valuable method. But, while it has often been urged that a scientific technique should be developed by careful research tests at various temperatures and with various kinds and amounts of peening (such as the severity and periodicity of the blows), it does not appear that this has yet been done in an adequate manner, studying the quality and the relative freedom from internally stressed conditions after different peening techniques have been employed. The appropriate temperature conditions should be determined as well as the location of the application of the peening blows. In multiple-layer welding, should the peening process follow each deposit? Peening may lead to better welding of high-carbon steel or of non-ferrous metals or their alloys."

3. Effect of Method of Making Welds upon Alloy Steels and Non-Ferrous Metals.

The problem of welding alloy steels is bigger, more comprehensive and complicated than that of welding carbon steel. With some alloying elements the question of heating is very critical as regards its effect on the density of the deposited metal. In this respect the limits of operating conditions may be narrower. The type of electrode used also affects the result. Considerable experimental work on welding nickel steel plate has been done at Watertown Arsenal.

4. Comparative Properties of Welds Made with Bare and Covered Wire.

5. Effect of Annealing on Locked-up Stresses in Welded Specimens.

The highest grade of welded construction which is approved by the new boiler code of the A. S. M. E. requires that all welded vessels be annealed, regardless of their size before placing in service. The treatment requires raising to a temperature of 1100° or 1200° F. Some investigative work has been carried out along this line to determine the effect of the annealing treatment and some good results have been presented in the welding trade magazines as well as the Welding Journal.

The principle which is generally used is to make a series of careful strain gage measurements before and after annealing, these being located in such a fashion as to reveal the effect of the treatment. With a proper regard for elastic and plastic deformation, an accurate measure of the residual stresses is obtained.

This work should be carried out on welds made by different processes and on various types of metal, as well as heating to different temperatures.

This problem would involve, essentially, heat treatment as well as strain gage measurements, and probably a few tensile tests.

6. Temperature and Technique for Strain Annealing of Various Types of Welds.

7. Speed of Welding and Relation of Amount of Current and Voltage.

NOTE: A record of the power consumption at the arc with these tests would provide definite information along a direction in which very uncertain information now exists.

8. Comparative Merits of Various Types of Welded Joints in Minimizing Strain.

9. Proper Welding Procedure to Obtain Satisfactory Welds in Hydrogen Atmosphere.

10. Effect of Size, Number of Layers, Length and Shape of Fillet Welds on Their Strength.

11. The Effect of Annealing (above and below the critical range) on the Physical Properties and Machinability of Welds. (Particular attention should be given to alloy and high-carbon steel.)

12. Effect of Speed (fast or slow welding) on Quality of Weld and Effect on Adjacent Material when Resistance Welding Different Steels and Non-Ferrous Metals and Alloys.

13. Study of Different Methods of Resistance Welding and the Effect of Such Welding on the Material Welded. (This should be done on different steels and non-ferrous metals and alloys.)

14. Effect on Resistance Welding of Coatings Such as Dirt, Oxide and Different Plating Such as Zinc, Cadmium, Lead, Tin, Chromium and Others When Applied to Steels and Non-Ferrous Metals and Alloys.

15. Penetration: Advantages and Disadvantages of Deep Penetration.

NOTE: This problem might be stated, "Is deep penetration necessary?"

It is of advantage to the industry to show that penetration need be no greater than necessary to make molecular union of the weld metal and the base material.

The experimenter should preferably be a welder in order that he could alternately weld and then study the effects of varying penetration on his welds. There are few experimenters who are expert enough in welding to make a proper job of this. Such a problem would have great usefulness and should be carried out in gas and arc welding.

It is probably safe to say that most practical welders desire to work with a set of conditions which will give deep penetration into the base metal when carrying out a weld. The origin of this conception undoubtedly dates

to the earlier development period of welding, and the practice has undoubtedly become widely accepted because deep penetration would somewhat naturally become associated with more complete fusion at least in the mind of the average welder. Deep penetration would have the psychological effect of giving him more assurance that complete union between the applied metal and the base metal had been effected.

In later years, as welding has advanced into various industrial fields where it has met with more keen competition, the question has arisen in the minds of many engineers as to whether the idea of deep penetration should not be modified, and it is in answer to this question that this problem of fundamental research is proposed.

Generally speaking, with any one set of conditions in electric welding, for example, on a certain plate thickness with a certain electrode diameter, current density and polarity, the extent to which the base metal is melted under the arc is very close to a constant amount. With many standard electrodes now on the market, this penetration is a fairly measurable distance. If the polarity should be changed and all other conditions remain the same, there will be a tendency for less deep penetration due to less heat being liberated on the plate when it becomes negative. However, in the case of reversed polarity, it seems quite usual to obtain a satisfactory weld, although the penetration is not so deep. The question naturally arises as to how deep this penetration should be and if there are any means at hand to control the penetration to a certain satisfactory depth.

The writer cannot at the moment conceive of any simple means to control the depth of penetration except by using some cooling device to keep the base metal cold enough to resist the melting effect of the arc crater. The difficulty of carrying on an investigation in electric welding would depend upon how successful were the means for controlling this depth of penetration.

Assuming that such a means should be devised, there would naturally follow a series of physical tests on the weld metal and on the base metal in the region of the weld to determine if depth of penetration had any advantage or disadvantage upon these two different metals in the welded region.

The same general remarks apply in regard to gas welding, and a similar series of tests should be conducted with the same objects in view. It is of interest to note that one recently developed process in gas welding, known as the Linde process, in which an excess acetylene flame is used along with a certain technique, is stated to give less penetration that any other fusion welding process. Indeed, it has been stated that no fusion of the base metal need actually take place in order to secure perfect union of the applied metal and the base metal. To a somewhat lesser extent, the atomic hydrogen process would serve the same purpose and might be utilized with various devices which the experimenter would develop in order to study the problem of penetration.

16. Investigate the Weldability of Different Grades and Thicknesses of Copper by Using Different Filler Rods and Welding Processes. Work Up a Welding Technique for Each Suitable System of Variables and Compare the Different Processes by Making Physical Tests on the Welds.

Group E—Structural Studies

1. Tests on Various Types of Connections of Beams Welded to Columns.

2. Resistance of Welded Joints to Variable Loads. It is suggested that for this item methods of testing can be devised which can be carried out easily. It is also necessary to classify the various types of loading, producing variable stresses in welded joints. These variable stresses occur in bridges, crane runways, ships and possibly other important structures.

3. Photoelastic Studies of Stresses in Welded Joints.

Because of the rapidly widening application of welding to all forms of construction, there has arisen a need for reliable analytical methods for studying the stresses set up in welded joints.

There has come to the forefront in recent years a photoelastic method for treating this subject. Generally speaking, it consists of studying, by means of polarized light, the stresses set up in xylonite models. This method has proved its usefulness by explaining apparent irregularities in stress conditions.

If any laboratory should desire to take up this method of stress analysis, the American Bureau of Welding will be glad to submit designs of various types of joints that lend themselves to this method of analysis.

In photoelastic work it is suggested that three types of specimens that form part of the program of the Structural Steel Welding Committee would produce interesting results. These are as follows:

I. Butt joints with intermittent welds, Series 3800, 3900 or 4000.

II. Diagonal butt joints with intermittent welds, Series 4400 to 5200.

III. Single tee joints with fillet welds in parallel shear, Series 5700. This type of joint can be tested by placing it first in a horizontal position and then in a vertical position so as to measure the stresses in both planes.

The material used should be a grade of celluloid called xylonite.

It should have been well seasoned preferably for three or four years.

A thickness of $^3/_{16}$ in. or $^1/_4$ in. has been found to give satisfactory results.

4. Experimental Check on Theoretical Methods of Computing Stresses in Welded Joints.

Group F—Problems Involving Chemistry

1. Relations between Chemical Composition, Mechanical Properties and Weldability of Steel.

2. Viscosity Melting Point and Surface Tension of Coatings (Slags) for Electrodes.

3. Corrosion of Welds.

Group G—Psychological

1. A Psychological Study of the Effect of Continued Welding on the Operator, with Particular Reference to the Effect of Fatigue on the Quality of Welding.

Library Research

Arrangements are at present being made for Library Research on various important welding subjects. It is believed that, without in any way reflecting upon the value of Laboratory Research, a given outlay on Library Research may, in many fields of investigation, advance our knowledge at least as much as an equal expenditure on Laboratory Research. Possibly men of different temperament and training will be found most effective in each of these two respective kinds of research activity and the kinds of problems best solved by Library

Research will be different from those which should be solved by Laboratory Research.

But the present is an excellent occasion for a demonstration of the value of the heretofore terribly neglected Library Research method, since many of the ablest addicts of Laboratory Research, while at present (owing to the world economic dilemma) debarred from its practice, can transfer their activities to well-equipped Libraries and salvage submerged facts and data and build upon this material, important truths, conclusions and discoveries.

This may, after the return of more normal economic conditions, lead to a much more intensive use of Libraries and there will be, in Laboratory Research, less (unintentional) waste in repeating, at great expense, already well-made experiments and in learning, by expensive tests, truths which would dawn upon the Library Researcher as the result of his intelligent study of published data concerning the underlying facts.

Conclusion

The Committee will greatly appreciate cooperation from those interested in these subjects in the form of additional suggestions, opinions and comments to follow the particular titles in the list below, to which they respectively relate. These communications should be sent to Mr. W. Spraragen, the Committee's Secretary, at 29 West 39th Street, New York, N. Y.

List of Forty-One Undertakings Associated with the Fundamental Research Committee of the American Bureau of Welding and the Engineering Division of the National Research Council

Research Being Conducted by	Affiliation	Name of Chairman of Local Section (Where Thus Organized)	Subject of Research
(1) Mr. Peter Alexander	Thomson Research Laboratory of G. E. Co. at Lynn	J. P. Walsted	Testing welds with gamma rays
(2) Prof. Edward Bennett	University of Wisconsin		Studies relating to the selective heating of large conducting bodies in strips by utilizing the "proximity effect" to control the distribution of heating currents of the audio frequency range
(3) Prof. A. H. Beyer	Columbia University, Dept. of Civil Engineering	J. M. Keir	Analysis by photoelastic methods of the stress distribution in welded connection
(4) Dean C. P. Bliss	Dean of College of Engineering of New York University	J. M. Keir	
(5) Prof. H. M. Boylston	Case School of App. Science, Dept. of Metallurgy	C. H. Jennings	(*a*) Metallurgical investigations on welds (*b*) Factors influencing the welding quality of steel
(6) Prof. Hemenway R. Bullock	Mass. Inst. of Technology	J. P. Walsted	Effect of oxygen on weld metal, particularly as affecting the distribution of pearlite in the microstructure. Also obtaining electrical engineering data concerning changes in microstructure at stress relieving temperatures
(7) Prof. F. Creedy	Lehigh University, Dept. of Electrical Engineering		Physics of the arc
(8) Prof. L. H. Crook	Catholic University, Washington, D. C.		Strain-gage measurements
(9) Prof. D. J. Demorest	Ohio State University	C. H. Jennings	(*a*) Effects of annealing upon the relieving of strain after welding (*b*) Flux coatings to improve welding qualities (*c*) Non-destructive tests for welds by magnetic methods, X-ray and radium ray
(10) Prof. Gilbert Doan	Lehigh University, Dept. of Physical Metallurgy		(*a*) Nitride needles as affecting age-hardening properties (*b*) A study of metal transfer during arc welding (*c*) A study of pure iron electrodes in pure argon and in air (*d*) A study of volt-amp. characteristics of the pure iron arc (*e*) The use of gamma rays for weld examination (*f*) Viscosity melting point and surface tension tests
(11) Mr. R. F. Edgar	University of Pittsburgh, Dept. of Civil Engineering	C. H. Jennings	Shear stresses in welds
(12) Prof. S. L. Goodale	University of Pittsburgh, Dept. of Metallurgy	C. H. Jennings	Coatings on wire
(13) Prof. A. Haertlein	Harvard University	J. P. Walsted	
(14) Prof. P. R. Hall	Penna. State College, Dept. of Industrial Engineering	C. H. Jennings	Weldability of cast iron

	Research Being Conducted by	Affiliation	Name of Chairman of Local Section (Where Thus Organized)	Subject of Research
(15)	Prof. W. A. Harvey	Lehigh University, Dept. of Metallurgical Engineering		Corrosive fatigue testing
(16)	Prof. Otto Henry	Brooklyn Polytechnic	J. M. Keir	Effect of low temperature on tensile strength of welded joints in steel
(17)	Prof. W. F. Hess	Rensselaer Polytechnic Institute		Magnetic characteristics of deposited metal
(18)	Prof. P. Hodge	Stevens Institute of Technology, Dept. of Physics	J. M. Keir	
(19)	Prof. T. P. Hughes	University of Minnesota, Dept. of Mechanical Engineering		Relation between ductility values as obtained from tensile and bend specimens
(20)	Mr. C. H. Jennings	Westinghouse Electric & Mfg. Co.	C. H. Jennings	Strength and design of welded joints
(21)	Prof. W. B. Kouwenhoven	Johns Hopkins University		Flux penetration tests
(22)	Prof. W. J. Krefeld	Columbia University, Dept. of Civil Engineering	J. M. Keir	Initial strains and residual stresses resulting from the heating incident to the welding operation
(23)	Dr. V. N. Krivobok	Carnegie Institute of Technology, Dept. of Physics	C. H. Jennings	Metallurgical properties of welds
(24)	Prof. T. R. Lawson	Rensselaer Polytechnic Institute; Head of Dept. of Civil Engineering		(*a*) Quantitative studies of the stresses caused by welding operations (*b*) The effect of annealing on the locked-up stresses in welded specimens and the comparative merits of various types of welded joints in minimizing strains (*c*) Photoelectric studies of stresses in riveted and in welded joints
(25)	Dr. H. H. Lester	Watertown Arsenal	J. P. Walsted	
(26)	Prof. P. M. Lincoln	Cornell University, College of Engineering		
(27)	H. J. Masson	Professor of Chemical Engineering	J. M. Kier	Corrosion fatigue tests of welded joints
(28)	Dean J. A. Needy	Ohio Northern University, School of Engineering	C. H. Jennings	Effects of peening on quality of welds
(29)	Prof. J. T. Norton	Mass. Inst. of Technology, Dept. of Mining and Metallurgy	J. P. Walsted	X-ray diffraction method for investigating stresses in welds
(30)	Prof. O. D. Rickly	Ohio State Univ., Dept. of Industrial Engineering	C. H. Jennings	Study of residual stresses in welded joints
(31)	C. T. Schwarze	Professor of Civil Engineering, New York University	J. M. Kier	(*a*) Use of bend test for measurement of ductility (*b*) Photoelastic studies of the stresses in welded joints
(32)	Prof. R. R. Seeber	Michigan College of Mining and Technology, Dept. of Mechanical Engineering		Copper welding
(33)	Prof. G. E. Thornton	State College of Washington, Dept. of Mechanical Engineering		Fatigue tests
(34)	Prof. J. P. Walsted	Mass. Institute of Technology, Dept. of Mining and Metallurgy	J. P. Walsted	Effect of nitrogen on welds
(35)	Prof. N. F. Ward	University of California, Dept. of Mechanical Engineering		Creep of welds, effects, distribution and methods of adjusting internal stresses due to welding
(36)	Mr. R. A. Weinman	Schenectady Research Laboratory of G. E. Co.		Fatigue tests
(37)	Prof. A. E. White	University of Michigan		(*a*) Practicable method for the inspection of welds (*b*) Creep properties of welded stock
(38)	Prof. W. R. Woolrich	University of Tennessee		(*a*) Improving welds by peening (*b*) Effect of magnetic and electric fields on metal deposition
(39)	Dr. M. Yatsevitch	Watertown Arsenal	J. P. Walsted	Coefficient of expansion of weld metal
(40)	R. P. Davis	Dean, West Virginia University		Welded structural members
(41)	R. E. Jamieson	Prof. of Civil Engineering, McGill University, Montreal		Internal stresses caused by welding

Tests of Joints in Wide Plates*

By WILBUR M. WILSON, JAMES MATHER *and* CHARLES O. HARRIS

†This is a report of an investigation conducted by the Engineering Experiment Station, University of Illinois, in cooperation with The Chicago Bridge and Iron Works.

I. Introduction

Object and Scope of Investigation.—The object of the investigation was to determine the efficiency of various types of joints in wide plates as used in the construction of storage tanks for water and oil. The investigation included tests of: (1) riveted lap and butt joints; (2) joints for which the holes were drilled and others for which they were punched; (3) joints with rivets in single shear and others with rivets in double shear; (4) welded joints, both lap and butt; (5) joints having rivets supplemented with welds; and (6) wide plates containing no joints. The section of the plates varied from 40 in. x $^1/_4$ in. and 20$^1/_2$ in. x $^1/_2$ in. to 72 in. x $^5/_8$ in. In addition to determining the ultimate strength of the specimens, measurements were taken to determine variations in strain in the plate along the seam and, in the case of riveted joints, to determine the slip of the rivets at various points. The physical properties of the material from which the joints were made were determined from standard tension tests of pieces cut from the plates used in making the specimens. Rivets taken from the same lot as the ones used in making the specimens were tested as individual rivets, some in single and others in double shear. [EDITOR'S NOTE: Only those tests which relate to welding are included.]

II. Description of Tests

Description of Apparatus.—The smaller specimens of the 1928 series were tested in a 600,000-lb. Riehlé testing machine and the larger specimens of the 1930 series in a 3,000,000-lb. Southwark-Emery machine. Each machine was equipped with special pulling heads each of which consists of a pulling bar that is gripped in the jaws of the testing machine at one end and that is pin-connected on the other end to a built-up clevis consisting of wide plates containing holes to match corresponding holes in the ends of the specimen. The specimen was fastened between the two plates forming the clevis with machine bolts. The pin was provided to insure centric loading and the wide rigid clevis distributed the load across the width of the plate, that is, along the length of the joint.

Flame Cut Edges.—The following tests were made to determine whether flame cutting injures a plate: The parent plate was cut into strips by burning along the full lines. Specimens A2 and A3 were tested as finished with the torch, except that projecting beads were knocked off. Specimens A1 and A4 were machined to the dotted lines, all material that was heated being removed. Specimens B1, B2, B3 and B4 were cut from a second plate in the same manner. The results of the tests are given in Table 1. These tests indicate that flame cutting increases the strength of narrow specimens slightly and reduces their ductility. The relative effect on a specimen 20 in. wide would not appear to be appreciable and it is believed that the difference in behavior between the two groups is not due to the manner in which the edges of the plate were cut.

Table 1—Effect of Flame Cutting upon Properties of Steel Plates

Specimen No.	How Cut	Reduction of Area, Per Cent	Elongation in 8 In., Per Cent	Yield Point, Lb. per Sq. In.	Ultimate Strength, Lb. per Sq. In.
A1	Machined	60.0	27.75	37,200	62,400
A4	Machined	57.9	30.25	36,400	62,300
Average		59.0	29.00	36,800	62,350
A2	Flame-Cut	42.7	20.38	41,100	64,700
A3	Flame-Cut	49.7	21.25	39,900	63,800
Average		46.2	20.81	40,500	64,250
B1	Machined	56.4	33.13	37,100	59,100
B4	Machined	60.4	31.25	37,600	60,900
Average		58.4	32.19	37,350	60,000
B2	Flame-Cut	46.2	20.50	40,800	63,500
B3	Flame-Cut	42.4	24.38	40,500	63,200
Average		44.3	22.43	40,650	63,350

Strength of Welds.—Two specimens having welded lap joints and two combination weld-and-riveted lap joints were tested in the 1928 series. The specimens have the same general dimensions as those shown in Fig. 1. The section at the middle is 20$^1/_2$ in. x $^1/_2$ in. and the rivets have a nominal diameter of $^3/_4$ in. The results of the tests are given in Table 2. The failure of the rivets to add materially to the strength of the joint consisting

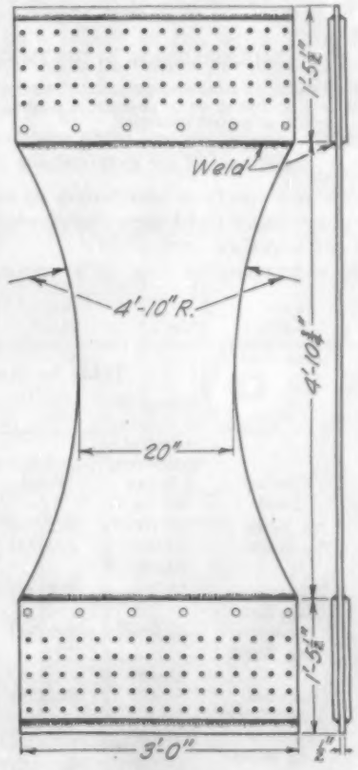

Fig. 1—Typical Specimen of 1928 Series

* Abstracts from Bulletin No. 239, University of Illinois.

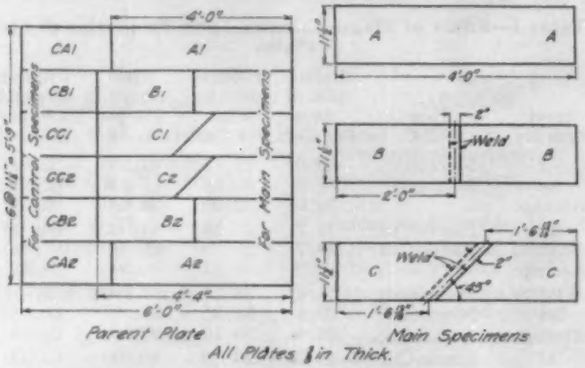

Fig. 2—Parent Plate and Welded Lap Joints for 11½-in. Specimens, 1930 Series

Table 2—Strength of Welded Lap Joints, 1928 Series

Specimen Number	Kind of Joint	Ultimate Strength, Lb.	Ultimate Load in Lb. per In. Length of Bead	Strength of Control Specimens, Lb. per Sq. In.	Efficiency* of Joint, Per Cent	Manner of Failure
SAA	Rivet and Weld	451,600	22,030	52,192	84.42	Plate tore outside of joint
SAB	Rivet and Weld	420,000	20,490	51,761	79.16	Weld failed
SAC	Rivet and Weld	454,000	22,150	51,879	85.38	Weld failed, followed by plate
Average		441,867	21,550	51,944	82.99	
SCA	Weld	428,000	20,880	57,277	72.85	Weld tore
SCB	Weld	401,000	19,560	50,908	76.85	Weld tore
SCC	Weld	426,000	20,780	54,393	76.41	Weld sheared from plate
Average		418,333	20,450	54,193	75.37	

* Efficiency of joint is ratio of actual strength to product of area of gross section and unit strength of control specimens.

of both welds and rivets is attributed to the fact that the weld is much more rigid than the rivets, so that the two did not act together.

Two wide specimens of the 1930 series contained welded butt joints. The plates were 64 in. x ⅝ in. In preparing the plate for welding the ends were machined to a bevel of 60 deg. and a backing strip was used. After the bead had been run the backing strip and the bead were chipped flush with the plate so that the section through the weld was the same as through the original section of the plate. The weld was made with a hand-operated electric arc and a coated* rod was used. The ultimate strength for the two specimens was 2,050,000 and 2,100,000 lb., respectively. Specimen AW1 broke outside of the weld and AW2 in the weld, although the latter developed a higher stress than the former. The efficiencies for the two specimens were 96.4 and 99.4 per cent, values that compared favorably with the efficiencies of wide plates of from 85 to 98 per cent. The width of the specimens decreased from 64 in. to 60½ in. for AW1 and to 61½ in. for AW2.

Specimens containing welded lap joints in plates 11½ in. x ⅜ in. were included in the 1930 series. These plates were welded in the vertical position to simulate the field conditions encountered in assembling a tank. Figure 2 shows the dimensions of the specimens and also the parent plate for these specimens. The plates A1 and A2 are full width control specimens. Control specimens 1½ in. wide were cut, one each from CA1, CA2, CB1, CB2, CC1 and CC2. The results of the tests are given in Table 3. The specimens having a transverse weld developed 92.74 per cent of the strength of the wide plate without joint whereas the specimens having a diagonal weld developed 99.90 per cent of the strength of the continuous plate.

The difference between the efficiencies of the joints reported in Tables 2 and 3 is attributed to the development in the art of welding during the period between the dates when the two series of tests were made, particularly to the development in the shop where these specimens were made. There was some development in apparatus and in welding rods but of considerably more importance was the development of experience and skill on the part of the welder. The quality of hand welding must of necessity depend primarily upon the skill and integrity of the workman. The quality of weld made by one workman is no indication of the quality of weld that will be made by another workman using the same rod and the same apparatus.

* A "coated rod" as the term is used in this bulletin is a rod having a composition such that an inert gas is developed when the rod is melted which is supposed to protect the molten metal from oxidation. Rods having a coating that serves as a flux are not "coated rods" in the sense in which the term is used in this bulletin.

Table 3—Strength of Welded Lap Joints, 1930 Series

Specimen Number	Kind of Joint	Strength of 1½-In. Control Specimens, Lb. per Sq. In.	Ultimate Load, Total Lb.	Ultimate Load, Lb. per Sq. In.	Efficiency of Weld Based on A1 and A2 as 100, Per Cent	Reduction of Area, Per Cent	Type of Failure
A1	No Joint	55,100	227,100	53,500	....	35.30	
A2	No Joint	52,390	219,200	52,500	....	39.50	
Average		53,745	....	53,000	....	37.40	
B1	Transverse Lap Weld	55,220	218,000	51,300	96.90	21.60	Transverse failure at edge of weld
B2	Transverse Lap Weld	55,590	199,500	47,000	88.68	20.90	Transverse failure at edge of weld
Average		55,405	....	49,150	92.74	21.25	
C1	Diagonal Lap Weld	55,460	222,000	51,500	97.17	35.00	Transverse failure beginning at end of weld
C2	Diagonal Lap Weld	55,080	227,700	54,400	102.64	34.20	Transverse failure beginning at end of weld
Average		55,270	....	52,950	99.90	34.60	

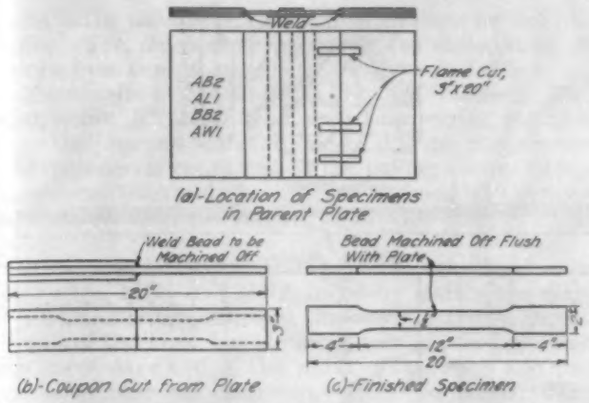

Fig. 3—Specimens for Determining Effect of Arc Welding upon Strength of Plate

Strength of Diagonal Joints.—Two types of specimens contained diagonal joints, one type was a welded lap joint and the other a riveted lap joint. The strength of the welded joint is given in Table 3. It developed an efficiency, based on the strength of a plate similar to the one welded, of 99.90 per cent.

Effect of Arc Welding upon the Strength of Plates.—Tests were made of standard tension specimens cut from the wide plates AW1, AB2, BB2 and AL1 of the 1930 series to determine the effect upon the main plate of the weld by which the side plates are attached. Figure 3*a* shows the location of the specimens in the parent plate, 3*b* shows the position of the weld and 3*c* the finished specimen.

The results of the tests are given in Table 4. The fact that all specimens broke two inches or more from the weld, indicates that welding the side plates to the main plate did not injure the latter.

Strength of Field Welds, 1931 Series—Uncoated Rods.—Joints of four wide plates were welded under field conditions encountered in the erection of storage tanks for oil and water.

Table 4—Effect of Arc Welding upon Strength of Plate

Specimen Number		Strength of Welded Specimen Lb. per Sq. In. Yield Point	Strength of Welded Specimen Lb. per Sq. In. Ultimate Strength	Strength of Control Specimen Lb. per Sq. In. (See Table 7) Yield Point	Strength of Control Specimen Lb. per Sq. In. (See Table 7) Ultimate Strength	Remarks
AW1	1	30,070	52,800	...	...	
	2	30,250	53,800	...	...	
	3	29,100	52,550	...	...	
	Average	29,810	53,050	27,760	53,290	
AB2	1	32,500	62,200	...	...	
	2	35,100	67,000	...	...	
	3	33,700	63,300	...	...	
	Average	33,770	64,170	39,940	64,880	
BB2	1	35,750	64,200	...	...	
	2	35,750	64,750	...	...	
	3	34,900	64,100	...	...	
	Average	35,470	64,350	32,290	64,580	
AL1	1	31,900	58,200	...	...	
	2	33,700	60,100	...	...	
	3	32,800	57,900	...	...	
	Average	32,600	58,730	30,140	58,850	

All specimens failed two inches or more from the weld

The plates for each specimen had a section 72 in. x $^1/_2$ in. Two specimens were butt and two were lap joints. All specimens were hand welded with the plates in a vertical position and so placed that the bead was vertical. A different workman welded each specimen, using an uncoated weld rod. The position of the main plates and of the control specimens in the parent plate, as well as the details of the two types of field welds, are shown in Fig. 4. The physical properties of the material as obtained from control specimen are given in Table 5.

The results of the tests are given in Table 6. Both butt welds failed in the weld, the efficiency of B1 being 80.31 per cent and of B2, 72.78 per cent. Of the two lap welds, A1 failed by tearing the plate about 20 inches from the weld. This wide plate had an efficiency of 86.08 per cent, based upon the strength of the control specimens $1^1/_2$ in. wide. Specimen A2 failed at the weld but the failure was due to tearing of the plate rather than to a failure in the weld. The failure was unusual in that for a portion of the joint it followed one weld and for the remaining portion it followed the other. A piece about $2^1/_2$ in. wide and 6 in. long tore free and fell out of the main plate leaving a hole. This specimen developed an efficiency of 94.11 per cent.

Table 5—Physical Properties of Material for Field Welds

Specimen Number	Control Specimen	Yield Point, Lb. per Sq. In.	Ultimate Strength, Lb. per Sq. In.	Elongation in 8 In., Per Cent	Reduction of Area, Per Cent
A 1	1	35,640	65,250	28.13	51.72
	2	34,460	64,000	26.75	52.01
	Average	35,050	64,310	27.44	51.87
A 2	1	31,880	58,450	29.63	54.20
	2	31,040	58,330	30.00	55.36
	Average	31,460	58,390	29.82	54.78
B 1	1	35,920	66,900	25.37	51.84
	2	35,530	66,770	22.75	53.35
	Average	35,730	66,890	24.06	52.60
B 2	1	34,800	65,710	26.63	53.45
	2	34,870	65,800	25.25	50.53
	Average	34,840	65,760	25.94	51.99
AW 1 1932	Average of 4	36,100	59,900	31.8	64.7
AW 2 1932	Average of 4	36,100	59,500	32.4	63.3
XY 1	Average of 4	30,100	56,800	32.3	63.5
XY 2	Average of 4	30,000	56,900	31.7	60.9
MN 1	Average of 4	29,900	56,900	31.3	61.8
MN 2	Average of 4	30,600	57,100	30.5	61.4
OP 1	Average of 4	29,900	56,900	32.2	61.4
OP 2	Average of 4	30,400	57,100	31.7	60.2

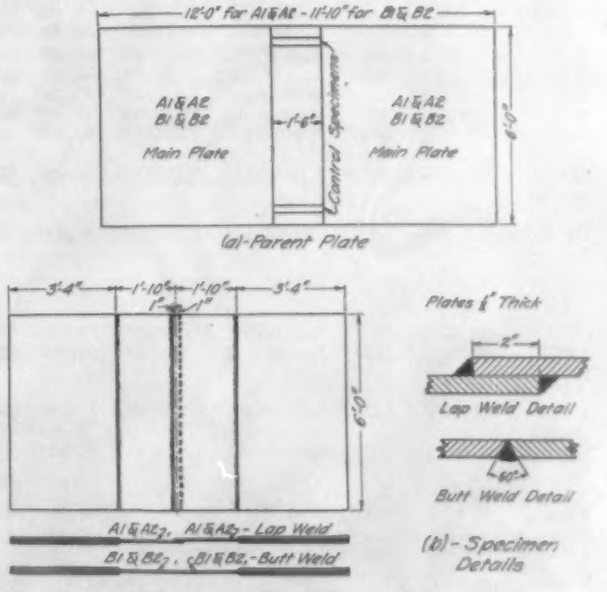

Fig. 4—Parent Plate and Details of Specimens for Field Weld Tests

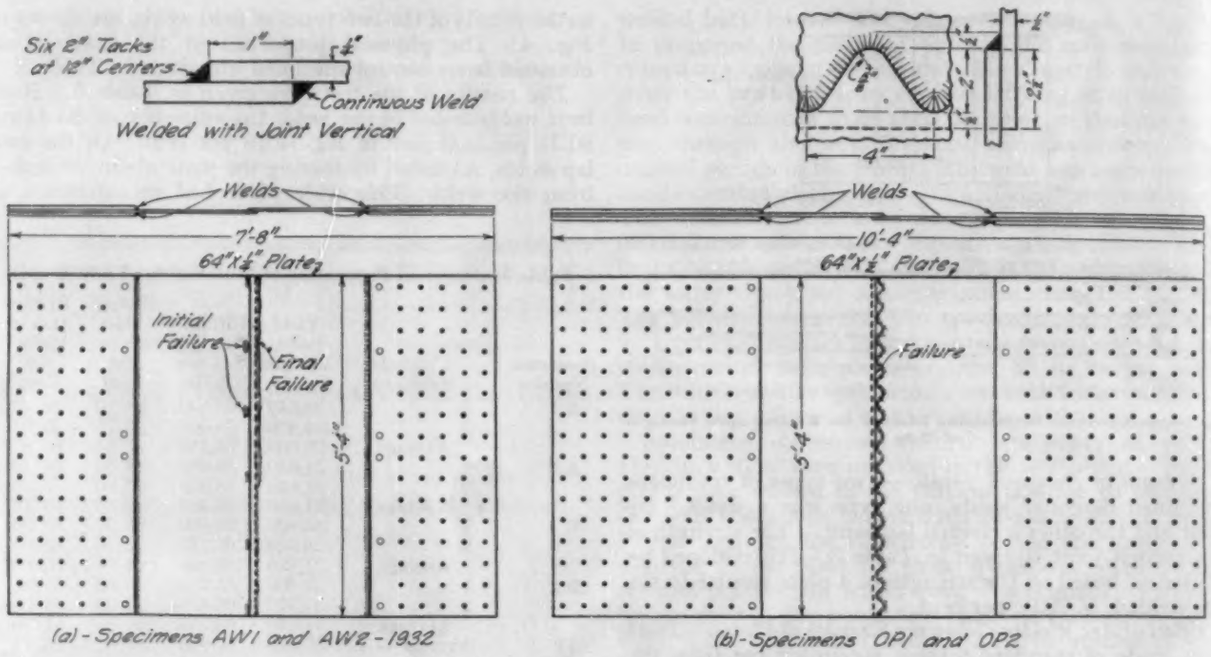

Fig. 5—Special Lap Joints

1932 Series—Coated Rods.—A second series of field-welded specimens were tested in 1932. This series included two specimens each of four types. Two specimens, MN1 and MN2, consisted of a lap joint, connecting two plates 64 in. x 1/2 in., the joint being similar to that in specimen A1 shown in Fig. 4, except that the plates were lapped 2 1/2 in.; two specimens, XY1 and XY2, consisted of a butt joint like B1 and B2, Fig. 4, connecting two plates 64 in. x 1/2 in.; two specimens, AW1—1932 and AW2—1932, contained the special lap joint shown in Fig. 5*a* connecting two plates 64 in. x 1/4 in.; and two specimens, OP1 and OP2, contained the special lap joint shown in Fig. 5*b* connecting two plates 64 in. x 1/2 in. All specimens except OP1 and OP2 were welded with the plates in a vertical position and so placed that the joint was vertical. The bead, however, was laid back and forth across the joint so that the pull on the specimen was parallel to the line of the bead. All joints were hand welded with a coated rod. The position of the main plates and of the control speci-

Table 6—Strength of Field Welds

Specimen No.	Section In.	Type of Joint	Ultimate Total Lb.	Strength Lb. per Sq. In.	Strength of Control Specimens, Lb. per Sq. In.	Efficiency of Joint, Per Cent	Elongation in 8 In., Per Cent	Reduction of Area, Per Cent	Remarks
A 1	72 x 0.498	Lap Weld	1,985,000	55,360	64,310	86.08	9.84*	7.21	Plate tore 20 inches from weld
A 2	72 x 0.503	Lap Weld	1,990,000	54,950	58,390	94.11	5.54*	4.06	Plate tore at weld
B 1	71.9 x 0.51	Butt Weld	1,970,000	53,720	66,890	80.31	4.34*	7.28	Weld failed
B 2	71.9 x 0.50	Butt Weld	1,720,000	47,860	65,760	72.78	2.21*	1.20	Weld failed
MN 1	63.81 x 0.504†	Lap Weld	1,665,000	51,900	56,900	91.3		1.67¶	Plate tore at top of weld starting at north edge
MN 2	63.81 x 0.503†	Lap Weld	1,722,000	54,600	57,100	95.7		1.67¶	Plate tore, the tear beginning at top of weld at north edge and extending up into plate
OP 1	64.12 x 0.504†	Lap Weld‡	1,495,000	46,300	56,900	81.5		0.97¶	Plate tore on a transverse section tangent to weld, the scallops being torn from the plate of which they originally formed a part. See Fig. 5*b*
OP 2	63.87 x 0.503†	Lap Weld‡	1,533,000	47,800	57,100	83.6		1.57¶	Same as OP 1
AW 1 1932	63.87 x 0.242†	Lap Weld‡	806,000	52,300	59,900	87.4		1.82¶	First tore at inside tacks, then tore at bottom of continuous bead starting at north edge. See Fig. 5*b*
AW 2 1932	63.87 x 0.243†	Lap Weld‡	734,000	47,300	59,500	79.6		1.08¶	Same as AW1
XY 1	63.87 x 0.503†	Butt Weld	1,655,000	51,500	56,800	89.0		2.74¶	Plate tore at end near junction with side plate. Similar to failure of 293C
XY 2	63.87 x 0.504†	Butt Weld	1,688,000	52,500	56,900	92.4		4.90¶	Same as XY1

* Failure did not occur in the length in which the elongation was measured.
† Thickness is average thickness of four control specimens.
‡ See Fig. 5.
¶ Reduction in width.

mens in the parent plate are similar to those for the 1930 series. The physical properties of the material as obtained from control specimens are given in Table 5.

The results of the tests are given in Table 6. Both butt welds, XY1 and XY2, failed by tearing the plate near the junction with the side reinforcing plates where the specimen is connected to the pulling clevis. These specimens developed efficiencies of 89.0 and 92.4 per cent comparable with the efficiencies of wide plates without joints.

Both plain lap welds having a continuous bead along each edge, MN1 and MN2, failed by tearing the plate. For MN1 the tear followed the weld for nearly the full length of the joint, for MN2 the tear followed the weld for about one-third of the width of specimen and then extended into the plate away from the weld. These specimens developed efficiencies of 91.3 and 95.7 per cent, respectively.

The two specimens, AW1—1932 and AW2—1932, containing lap welds having a continuous bead on one side and stitch-beads on the other, failed in the same manner. The plate first tore around the stitch-weld and then along the continuous bead as indicated in Fig. 5*a*. These specimens developed efficiencies of 87.4 and 79.6 per cent, respectively.

The two lap welds for which one edge was scalloped and the other straight, and which were welded on the scalloped edge only, specimens OP1 and OP2, both failed by tearing the plate on a transverse section tangent to the waved bead as shown in Fig. 5*b*. These plates developed efficiencies of 81.5 and 83.6 per cent, respectively.

Although all specimens failed by tearing the plates, the efficiency of the joints was less than 100 per cent. The plain lap-welded joints, MN1 and MN2, and the butt-welded joints, XY1 and XY2, developed efficiencies nearly equal to the efficiency of wide plates without joints. The lap-welded joints were slightly stronger than the butt-welded ones. The restraint to lateral flow offered by the joint probably caused the plates to fail at a load somewhat lower than the load which would have been carried by a similar wide plate without joint.

The greater strength developed by the field welds of the 1932 series over that developed by the similar field welds of the 1931 series is attributed to the difference in the weld rods used in the two series, the 1931 series having been welded with an uncoated rod and the 1932 series with a coated rod, both rods being manufactured by the same company.

III. Summary

Summary.—The tests reported in this bulletin apparently justify the following conclusions:

1. Continuous wide plates without joints (those tested were 20 in. x $^1/_2$ in., 40 in. x $^1/_4$ in. and 64 in. x $^5/_8$ in.) may be expected to develop a unit stress equal to approximately 90 per cent of the unit strength of control specimens (tension specimens, $1^1/_2$ in. wide). Two of the fifteen plates tested developed a unit stress less than 86 per cent of the strength of the control specimens.

2. The two welded butt joints in plates 64 in. x $^5/_8$ in. developed as great a strength as similar continuous plates without joints.

3. Welding side plates onto the main plate of the specimens did not weaken the main plate at the section where the weld occurred.

4. Of the welded lap joints in plates $11^1/_2$ in. x $^3/_8$ in., welded with the plates in a vertical position, the two with transverse welds developed 90 per cent and the two with diagonal welds developed 100 per cent of the strength of $11^1/_2$-in. x $^3/_8$-in. continuous plates without joints cut from the same parent plate as the pieces used for the welded specimens.

5. Of the field welds made with the bead in the vertical position, the two butt joints welded with an uncoated rod failed by breaking the weld, the efficiencies being 80.31 and 72.78 per cent, respectively; the two butt joints welded with a coated rod failed by tearing the plate, the efficiencies being 89.0 and 92.4 per cent, respectively. Of the lap joints with continuous welds, the two welded with an uncoated rod both failed by tearing the plate, one tearing at the weld and the other 20 in. from the weld. The efficiencies of the two specimens were 86.08 and 94.11 per cent, respectively. The two welded with a coated rod both failed by tearing the plate at the weld, the efficiencies being 91.3 and 95.7 per cent, respectively.

Discussion of Paper by C. A. Wills on "Welded Rolled Steel Design for the Iron and Steel Industry"

By R. A. BULL

✦Mr. Will's paper was presented at the Fall Meeting of the American Welding Society in Buffalo, Oct. 3, 1932, and printed in the September issue of the Journal. Mr. Bull is Director, Electric Steel Founders' Group.

NATURALLY, since I am a steel foundryman, my attention has been drawn to Mr. Wills' references to defects in castings in the first part of his interesting contribution. The nature of the fabricated parts described indicates that the author may have had chiefly in mind steel castings rather than other kinds of castings in briefly, but rather sweepingly, speaking of inferiorities which the author believes had much to do with economical substitution of welded assemblages for foundry products.

The art of manufacturing castings is a very old one. Considering the product of the foundry solely in respect to steel and confining our consideration of that product, for the present purpose, to manufacture in the United States, it is not in any sense surprising that a tremendous amount of improvement in the manufacture of steel castings has developed during the sixty-five year period of the industry's career in America, partly due, of course, to facts learned through the centuries in making other foundry products.

The writer of this discussion happens to have had intimate contact with the steel casting industry during about half of its existence in this country and, thus, has had the opportunity of witnessing many advances in practice which have made of the average steel casting of today a very different product from what it was during the first decade of the present century. The progress achieved is not realized by some persons who had unsatisfactory experience years ago with the average product of the steel foundry.

Practices serving to degasify the metal and to maintain the desired conditions within the mold for the production of thoroughly sound castings have brought about a condition of integrity which places the average steel casting of today on a plane much above that of the average deposit of weld metal in potential resistance to high stresses, in the judgment of the writer of this discussion.

Probably some mention should be made of opportunities for observing the relative conditions just indicated to justify comparisons now made in a spirit of fairness. It is not appreciated by all welding proponents that the average steel foundryman is and has been for many years conversant with welding practice. That is due to the use of welding as a repairing operation for many years. The writer's experiments in salvaging steel castings were responsible for the first motor-generator set made in this country exclusively for arc welding purposes. That pioneer unit was made by the General Electric Company in 1909. It is of some historical interest to record the fact that this equipment has never been discarded for the purpose prompting its purchase. The writer made many early tests in the use of gas and the arc for welding in the effort to repair steel castings having small defects before the motor-generator unit was developed. These experiments included the lowering of a shop voltage of 220, first by means of water-barrel rheostats, and later by the use of resistance grids.

Naturally, the steel foundryman wants to run his shop with the lowest possible percentage of scrapped castings while securing the best feasible condition of satisfactory appearance of the finished material. And, naturally, these considerations require that the steel foundryman keep informed regarding all welding developments and their results, in so far as they apply to the kind of welding that may usefully be done where castings are produced. Thus, generally speaking, the steel foundryman is cognizant of the condition of metal as ordinarily deposited in fusion welding, as he is of the condition in the average steel casting. Being in a neutral position, so to speak, the maker of steel castings, anxious as he is to save money in preventing and repairing defects in his product, wants to see welding develop along lines that afford continuously greater security. It may be remarked, without desire to make iron foundrymen uncomfortable, that there has been and will be a much more extensive substitution of iron castings than of steel castings in the economical substitution of welded assemblages for the product of the foundry.

Mr. Wills is laboring under a decided misunderstanding of present conditions when he believes (as he does, apparently) that the average steel casting as made today in the United States or Canada is apt to have blowholes, cracks and other defects to an extent that often makes the material unsatisfactory to the user. If Mr. Wills' own experience in these respects has been a sad one, it may be suggested that the source of supply happened to be an unfortunate selection. Such a condition is likely to result occasionally when the purchaser insists on buying strictly on a price-per-pound basis, apparently thinking that all steel castings made in some 275 American steel foundries are comparable in quality. Generally, one gets what one pays for. That applies in procuring castings as in obtaining the services of welding shops. Among the latter there are many hundreds today producing (as Mr. Wills doubtless realizes) a very great variety of welds in respect to soundness. Probably no welding advocate who is properly informed would deny that, in the very important factor of potential resistance to high stresses exerted directly in any chosen direction on metal deposited by welding, in all the shops in the United States where fusion welding is done regularly, there is a vastly greater variation in quality discovered than is found in the total tonnage of steel castings produced in any given period taken for the comparison.

Fortunately (for the actual benefit of the steel founder, among other persons) this objectionable condition is being steadily improved. But that holds true also of the manufacture of castings, as of forgings and other metal products, in all of which, be it said in fairness to everybody concerned, there has been very marked advancement made since the World War terminated. It is not difficult today to find welding shops where the factors of equipment or speed or ignorance or indifference, one or more in number, result in wider variation in quality of product than may be found with the same relative frequency in steel castings. This being so, it is quite out of place for one generally acquainted with metallurgical progress to attribute the merited advancement of welding fabrication along lines indicated by Mr. Wills largely to characteristic defects in steel castings. The real reason for such progress lies in the need for economical construction. That term is broadly inclusive and connotes what is good enough for the purpose and can be most cheaply produced and maintained under service conditions. And this, in turn, prompts dependence on the steel casting for a great many purposes for which no welding enthusiast is yet willing to advocate welded fabrication.

In verification of the steel foundryman's desire to see the average welding operation made more effective, it may be mentioned appropriately that numerous specifications for steel castings impose very important restrictions as to welding repair. And it has been observed that some consumers who are extremely reluctant to permit any such salvaging manifest a dependence on an assemblage made by fusion welding in a manner that creates amazement at the lack of consistency.

In justice to the steel casting, it should be mentioned in connection with data helpful to industry, contained in Mr. Wills' paper, that material weight reductions could unquestionably have been obtained in building many machines and structures where the product of the steel foundry has been the major or minor component, if in the past there had been the weight-consciousness that has been manifested by engineers in the recent development of many designs of welding equipment. And it is no more than fair to welders as a class for foundrymen and others to give due credit to those who advocate welding intelligently for the much better appreciation of the weight factor which exists today in numerous industries. In the past there has been considerable waste of metal, cast and wrought, as a result of excessive thicknesses of members. It is to the credit of welding engineers (who were chiefly prompted by important considerations of economical application of their own art) that a result of their exploitation has been the more satisfactory placing of metal where it is needed, while allowing a suitable factor of safety.

The welding engineer and the steel foundryman should nowadays dispassionately and diligently seek reliable information regarding all competitive products and exploit these with proper understanding and sense of proportion, endeavoring only to have their respective materials applied where, from an economic standpoint, they actually belong. If, in such efforts, the result happens to be prejudicial to any kind of cast or wrought part, or any result of a particular fabricating method, rivetted or bolted or welded, the loser will have to swallow his disappointment and become accustomed to the proper order of things.

Mr. Wills and his associates seem to have participated very helpfully in improving the designs of mill equipment.

Rebuttal to Discussion by R. A. Bull on Mr. Wills' Paper, "Welded Rolled Steel Design for the Iron and Steel Industry"

By C. A. WILLS

IT WAS disappointing to learn that Mr. Bull considered my paper as an attack on the usefulness and quality of steel castings, rather than a description of a growing interest in the art of welding and of the reasons for an increasing tendency to favor welded rolled steel designs.

I assume that Mr. Bull is familiar with the design, construction and service demands of the equipment described and, therefore, recognizes the necessity of careful scrutiny of the materials incorporated in the structures which are standard commercial products.

An inconsistency in Mr. Bull's statements in regard to steel castings makes it rather difficult to present comments on his very instructive discussion, inasmuch as he criticizes the implication in my paper that blowholes, cracks and other defects are often found in castings, and yet states that the foundryman is anxious to save money by repairing defects in his products by welding. What defects? Mr. Bull states it is possible that buying castings strictly on a price-per-pound basis might affect quality and that our selection of sources of supply might be unfortunate. Should these possibilities and uncertainties make it necessary to protect a product with higher factors of safety than ordinarily used? How can the fabricator eliminate the added factor of safety, improve his product and be reasonably sure of sufficient strength? Perhaps inspection by foundries of castings at critical points by the X-ray method of examination might prove economical to the fabricator.

In 1929 and 1930, 4,715,572 lb. of steel castings were incorporated in our products, and, to supply our customers with what we wanted them to have, it was necessary to return 385,261 lb. to the foundries for replacement, a rejection of 8.2%. Bills from us to the foundries for labor at cost for putting other castings in marketable condition during this period amounted to $1549.89. This amount did not include any charge for labor and machine work performed on castings returned to the foundries, all of which loss must be borne by the fabricator. During the same period, iron casting rejections amounted to 1.9% and rejections of rolled steel (which we use in much greater quantities) were 0.7%.

I agree entirely with Mr. Bull's statements in that many advances have been made toward producing sound castings, that dependence on steel castings for a great many purposes is absolutely necessary and that the real test of progress for any material or method of construction lies in the need for economical construction of satisfactory equipment; but I cannot agree that the using of material requiring rejections of 8.2% is economical. Neither do we believe welding is a "cure-all for every ill," as evidenced by the return—during two-year period—of 385,261 lb. of castings to the makers.

In regard to the reluctance of fabricators to salvaging castings by welding, our specifications to foundries do not permit welding by foundrymen, although we offer some products assembled by fusion welding. The reasons for such so-called inconsistency are that we insist on seeing why the castings need welding, wish to make our own decision as to whether or not welding is applicable to each specific case and prefer to do all welding for which we are ultimately responsible.

I do not consider my experience of thirty-six years with castings a sad and unsatisfactory one, but rather a typical one, and present the data given only with a view of acquainting interested parties with facts, and call attention to conditions which, when realized, demand improvement by some means if economies are to be obtained.

Inasmuch as we do and will continue to use castings, I appreciate Mr. Bull's discussion of my paper and thank him for the useful information therein.

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SECTION ACTIVITIES

(*Continued from page 4*)

Mr. H. B. Rice, Manager, Metal Spray Company, delivered a paper on "Metal Spraying—The Process and Devices and the Influence upon Welding." By means of slides Mr. Rice showed some interesting applications of the process. Lively discussion followed.

The November meeting of this Section was held on the 17th at the Mona Lisa Cafe. The subject of the meeting was Non-Ferrous Metals. Mr. J. R. Schmidgall, Sales Engineer, Aluminum Company of America, presented a paper on "Welding Aluminum and Aluminum Alloys;" and Mr. G. T. Piersol, Sales Engineer, The American Brass Company, spoke on "Welding Brass, Bronze and Their Alloys." Lively discussion followed the presentation of the papers.

NEW YORK

The members of the New York Section visited the Kearny Plant of The Federal Shipbuilding and Dry Dock Company on Saturday afternoon, November 5, 1932. Over ninety persons took advantage of the Company's invitation to inspect the new Grace Line boats being built at the yard.

The party was taken on board one ship on the ways where an excellent opportunity was afforded to see the various uses to which welding has been put in the construction. A sister ship, nearly completed, was also inspected. Other points of interest were the 8500-ton Floating Dry Dock, the Pipe Shop, the Machine Shop and the Power House.

The Company put forth every effort to make the visit an instructive and enjoyable one and the Section was fortunate to have had the opportunity to see the welding work being done in the Yards.

PHILADELPHIA

The regular monthly meeting of the Philadelphia Section was held on Monday, November 21st. Mr. J. Hartley, Engineer, Maintenance-of-Way, Pennsylvania Railroad, talked on "Welding of Battered Rail Ends," and Mr. George L. Young spoke on "Maintenance of Equipment by the Oxy-Acetylene Process." Both papers were most interesting and the meeting was very successful.

SAN FRANCISCO

The November meeting of this Section was held on the 22nd at the Russ Building. The subject of the meeting was, "Welding of Structural Steel as Applied in the New Hospital Building of the University of California, San Francisco." The design problems in the utilization of welding in this work were presented by Mr. W. L. Huber, Consulting Construction Engineer. The actual welding work was reviewed by Mr. W. P. Brown of Brown Bros. Welding Co. Inspection of structural steel welding was discussed by Mr. F. M. Randlett, Manager of Robt. W. Hunt Company.

PITTSBURGH

Over two hundred men attended the November meeting of the Pittsburgh Section of the AMERICAN WELDING SOCIETY held jointly with the Engineers' Society of Western Pennsylvania and the Pittsburgh Section of the A. S. M. E. to hear what A. F. Gibson, Vice-President, The Wellmann Engineering Company, Cleveland, Ohio, James Owens, Consulting Welding Engineer, Portsmouth, Va., and S. N. Clarkson, Managing Director, Welding Contractors Association of America, New York, had to say on welding.

The next meeting of the Pittsburgh Section will be held January 11th, at which Arthur Christen, Consulting Pipe Welding Engineer of Toledo, Ohio, will read a paper on how to further promote the application of pipe welding in buildings.

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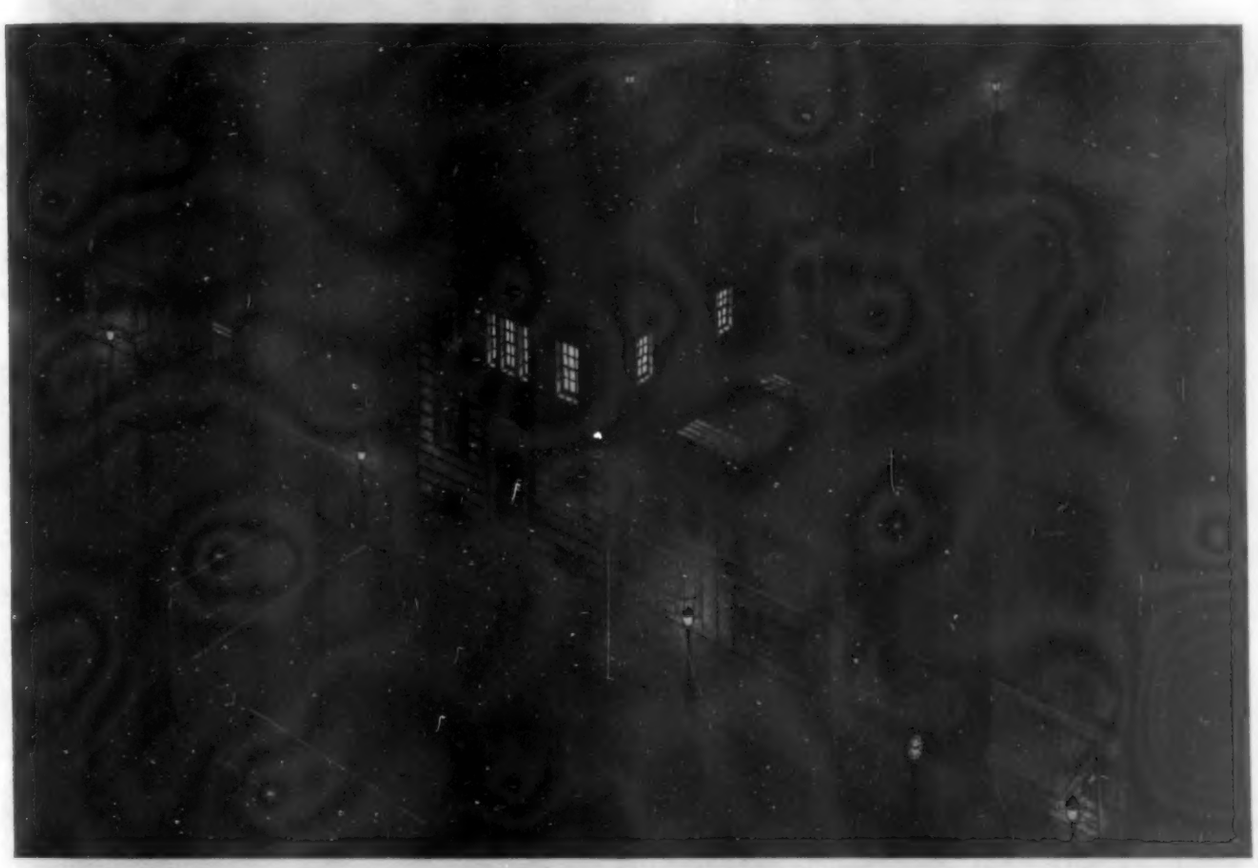

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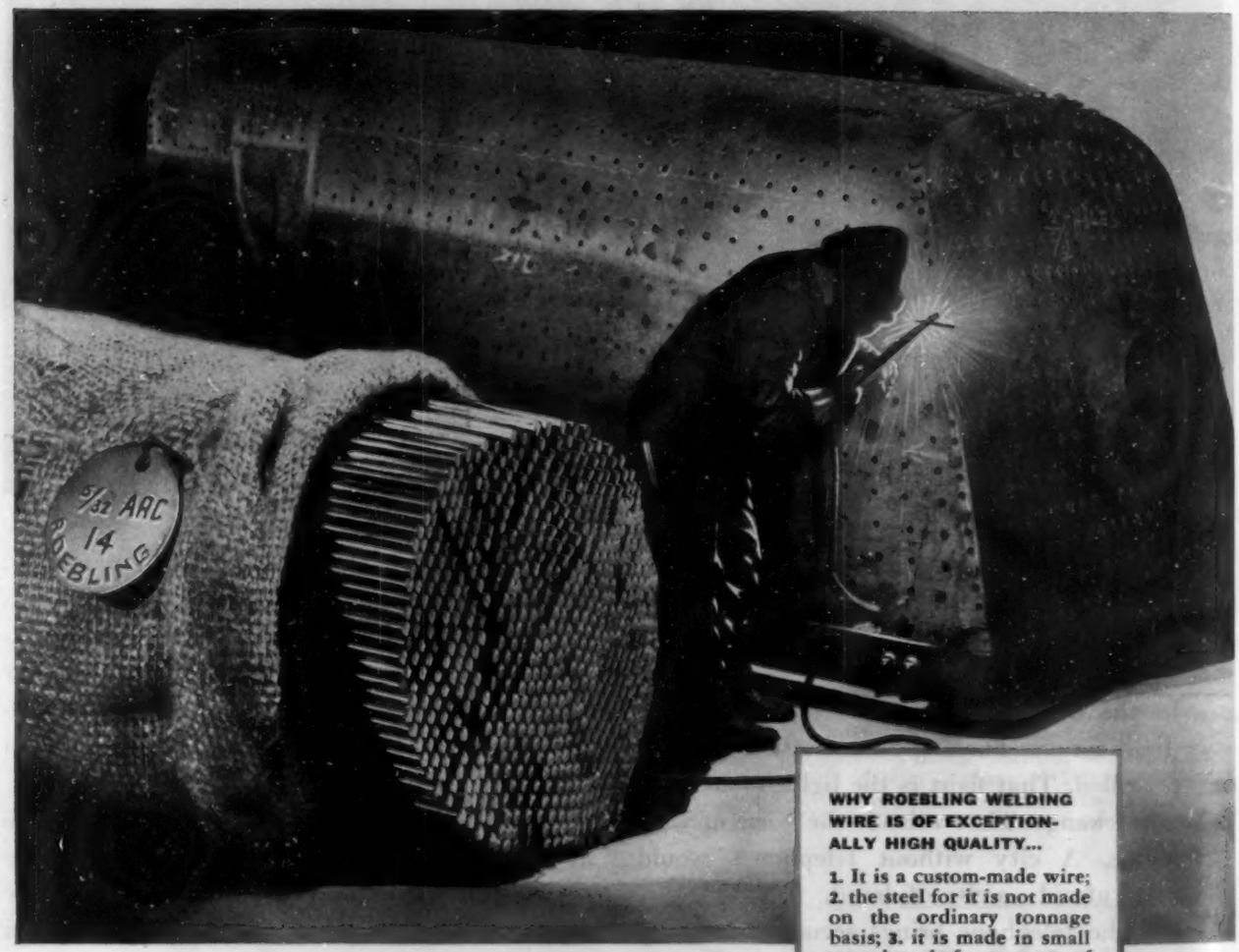

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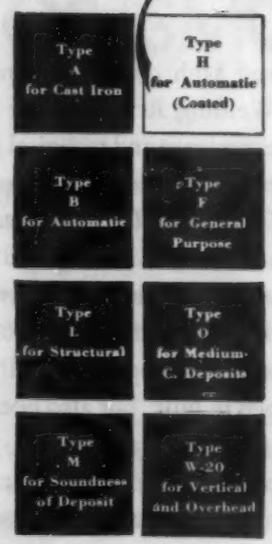
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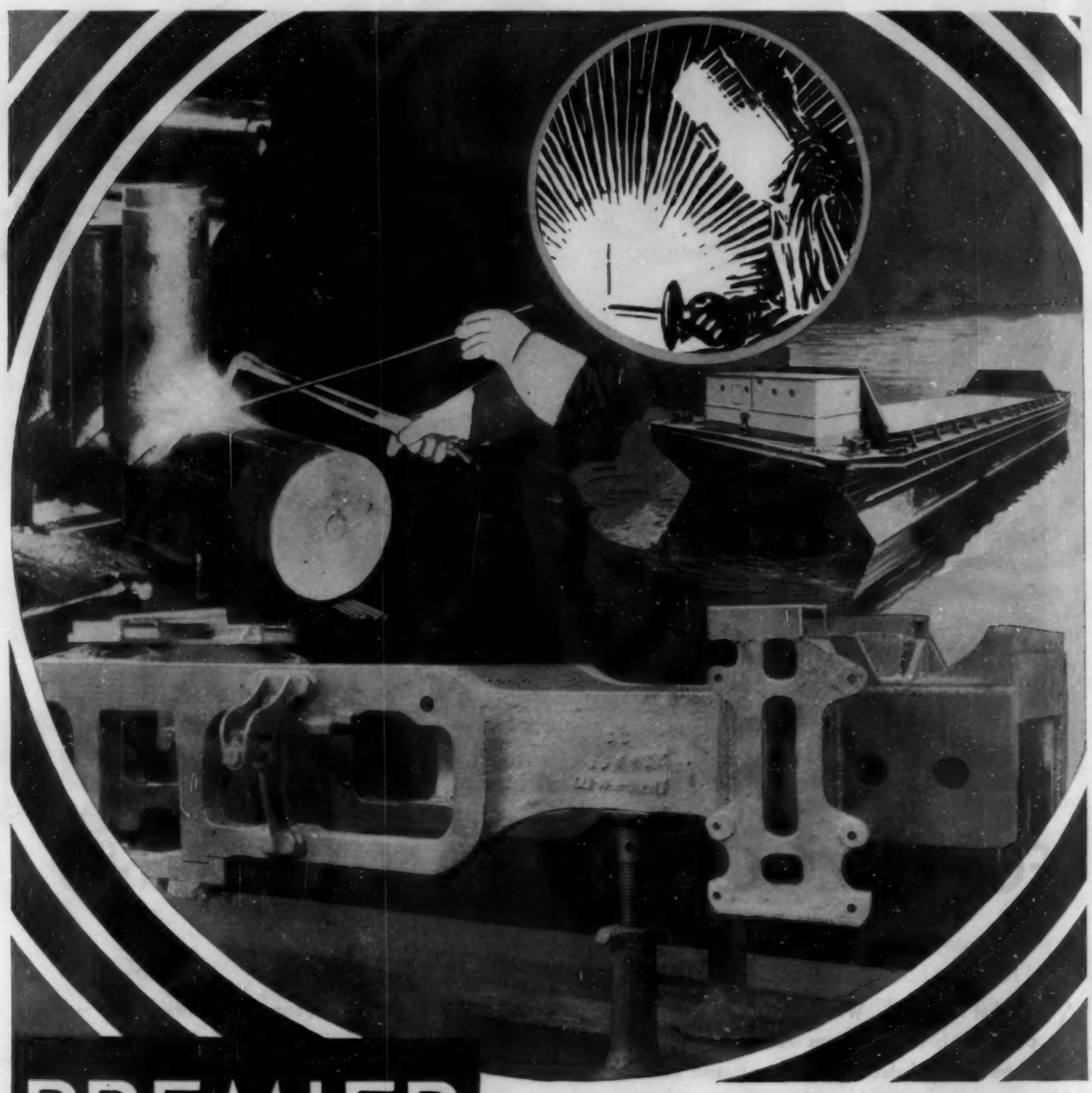

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Empire State Bldg., New York
First National Bank Bldg., Baltimore

Pacific Coast Distributors: Columbia Steel Company, Russ Building, San Francisco
Export Distributors: United States Steel Products Company, New York